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Release Constraint Limits 2016: Results from probabilistic analysis

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Abstract

During 2016 a review has been undertaken of the Release Constraint Limits (RCLs) currently used in Finnish nuclear regulations to assess potential risks to human health of releases to the biosphere of radionuclides disposed in geologic repositories. They are for use in the time period beyond a few millennia post repository closure when there are considerable uncertainties in the state of the biosphere system.

The current RCL values were derived in 2000 at a time when understanding of the characteristics of the biosphere at the site was less sophisticated than at present; details of Posiva's site characterisation programme are published and available to STUK. This material has formed part of the review of the derivation of the RCL values with a range of landscape objects types being identified.

Overall a revised set of release objects have been considered with revised model descriptions. Data has been derived from the landscape descriptive modelling and suitable probability distribution functions for key parameters for the landscape objects have been included. One of the purposes of this document is to set out the modifications to the models required for the probabilistic calculations and to catalogue the data used.

Results from the probabilistic modelling are used here to set out suggested revised values for RCLs and related quantities in future Finnish regulations. This report also provides commentary on how the revised values might practically be used.

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Avainsanat: radioaktiivinen jäte, päästöraja, radionuklidikulkeutuminen, biosfäärimallinnus, annosarviointi

Tiivistelmä

Vuoden 2016 aikana on suoritettu arvio koskien päästörajoja (Release Constraint Limits, RCLs), jotka on esitetty suomalaisessa ydin- ja säteilyturvallisuussäännöstössä. Niiden avulla arvioidaan geologisista loppusijoituslaitoksista biosfääriin vapautuvien radioaktiivisten aineiden aiheuttamia mahdollisia riskejä ihmisten terveydelle. Päästörajoja sovelletaan geologisen loppusijoituslaitoksen turvallisuuden arvioinnin raja-arvoina ajanjaksolla, joka alkaa usean tuhannen vuoden kuluttua laitoksen sulkemisesta, koska näin pitkällä ajalla biosfäärijärjestelmän tilaan liittyy merkittäviä epävarmuuksia.

Voimassa olevat päästöraja-arvot määritettiin vuonna 2000, jolloin tietämys laitospaikkakohtaisista biosfäärin yksityiskohdista oli vähäisempi kuin nykyään. Vuoden 2000 jälkeen Posiva on tuottanut ja julkaissut paljon tietoa laitospaikan biosfääristä ja se on ollut myös STUKin on käytettävissä. Tätä materiaalia on osaltaan hyödynnetty arviossa laadittaessa uusia päästöraja-arvoja huomioiden maastokohdetyyppien tunnistettu vaihtelu.

Tarkastelussa on käytetty päivitettyjä päästön kohteena olevia biosfäärin osia, joihin on sovellettu uudenlaisia mallikuvauksia. Lähtötiedot on saatu maastonkuvaus-mallinnuksesta ja tärkeimmille maastokohteita kuvaaville laskentaparametreille on sovellettu sopivaksi arvioituja todennäköisyysjakaumia. Tässä raportissa kuvataan päivitettyjen mallien todennäköisyyspohjainen laskenta sekä millaisia lähtötietoja laskennassa on käytetty.

Tässä raportissa esitetään uusilla todennäköisyyspohjaisilla malleilla lasketut päästörajojen arvot, joita voidaan hyödyntää säännöstön kehittämisen tukena. Raportissa esitetään myös näkökantoja, miten uusia arvoja voitaisiin käytännössä hyödyntää.

Contents

1 Introduction

1.1 Regulatory background

Depending on its origin and composition, concentrations of radioactive materials can pose a hazard far into the future. The radiological risk from very short-lived radionuclides – such as those used in medicine, with halflives of the order of days or shorter can be readily addressed. Procedures to assess the impact of such materials are relatively straightforward to formulate.

The potential impact of radioactive waste arising from industrial or technological sources (including nuclear power generation) can similarly be described in terms of the distribution and persistence in the biosphere. Waste disposal facilities for such materials are constructed so that the active material is contained until the activity has decayed to insignificant amounts. For many *short-lived* radionuclides, with halflives of a few tens to a few hundred years, the relevant timescale – around ten halflives – corresponds to a few millennia as the time required to allow the hazard to reduce to insignificance when compared to background radiation.

This timescale corresponds to most of documented human history, back to the end of the previous glacial period which ended around 12 kyear BP (before present). Much of the present surface environment of the planet has been shaped and remade over this timescale. With current understanding of features, events and processes (FEPs) in the biosphere it is possible to describe the future evolution of the biosphere with reasonable confidence over the next 10 kyear.

For those radionuclides with halflives greater than a few hundred years, including those which may grow-in from parent radionuclides during periods of containment, the problem is more complex. The Finnish Radiation and Nuclear Safety Authority, STUK, has issued guidance on the requirements for the assessment of long-term radiological risks of radioactive waste disposal (STUK, 2013).

From this guidance there are two time-regimes – upto "several millennia" wherein "account shall be taken of the changes in the living environment that arise from changes in ground and sea level" and the assessment period of a few millennia. Over the longer term, then,

The disposal of nuclear waste shall be so designed that, as a consequence of expected evolution, the average long-term quantities of radioactive materials released into the living environment from disposed nuclear waste remain below the constraints specified separately for each nuclide by the Radiation and Nuclear Safety Authority. These constraints shall be so defined that:

a. *at a maximum, the radiation impacts arising from disposal may be equiva-lent to those caused by natural radioactive materials in the earth's crust; and*
b. *on a large scale, the radiation impacts remain insignificantly low.*

The constraints shall apply to activity releases that may migrate to the living environment after several thousands of years at the earliest. These activity releases can be averaged over 1,000 years at the most. The sum of the ratios between the nuclide-specific activity releases and the respective constraints shall be less than one.

The reasoning behind specification of release constraint limits (RCLs) for long-timescale assessments is set out by Ruokola (2002).

The release rate of radionuclides from the repository to the environment, the geo–bio flux, was selected as the safety indicator for assessment periods beyond several thousands of years. The main reason for this choice was to exclude from the safety case the great uncertainties related to the evolution of the biosphere in the far future. It would be difficult for the implementer to defend the conservatism (as *required in our regulations) of any bioscenario and, as a consequence, the safety case might be based on extreme bioscenarios and overly pessimistic assumptions.*

This approach means that the burden on consideration of uncertainties related to evolution of the biosphere in the very long term rests on the rulemaker. He must consider what is a reasonable bioscenario when preparing his regulations, in particular when deriving the geo–bio flux constraints. The implementer need not consider very far future bioscenarios when preparing his safety case.

In short the RCLs are used by the regulator to avoid the complexities and uncertainties of modelling radionuclide distributions and exposures in the far future.

STUK (2013) specifies dose constraints that apply in the first few millennia post facility closure. The maximum annual individual dose is set to 0.1 mSv year. This can be compared with the annual average radiation dose to the Finnish population of 3.2 mSv year^{-1} (STUK, 2015).

There is therefore already an in-built conservative bias based on the 0.1 mSv year^{-1} constraint. The RCLs are then derived by working backwards from exposure to source-term for simplified bioscenarios (scenarios for exposure in the biosphere) so as to be able to define the appropriate geo–bio flux (the release rate from the geosphere to the biosphere).

The release constraints currently employed are summarised in Table 1. These are as reported by Ruokola in the 2002 publication. The bioscenarios used at the time to define the RCLs were selected to be:

- Use of a shallow well; household water, garden irrigation and domestic animal watering
- Use of a small lake; fishing, irrigation and grazing at shore
- Use of the sediment of a drained lake; agriculture and soil improvement.

In the intervening period between the definition of these RCLs and the present day there has been significant development in the understanding of FEPs that describe the present day and future biosphere conditions in Finland, accounting for the evolution of the landscape over the next few millennia. Sites in both Finland (Posiva, 2013) and Sweden (SKB, 2011; 2014a) have been studied.

Table 1. Geo-Bio flux constraints (RCLs – Release Constraint Limits) in the 2013 STUK guidance (STUK, 2013). Numerical values based on Ruokola, 2002.

nuclide	RCL GBq a^{-1}
Cm-245	0.03
Am-243	0.03
Pu-239	0.03
Np-237	0.1
U-238	0.03
Pa-231	0.03
Th-229	0.03
Ra-226	0.03
Sm-151	100
Cs-135	0.3
I-129	0.1
Sn-126	1
Pd-107	100
Nb-94	1
Se-79	0.1
Tc-99	3
Zr-93	10
Ni-59	30
Cl-36	0.3
C-14	0.3

The RCLs reported by Ruokola in 2002 were based on the then current best understanding of FEPs in the Finnish context. However this included the use of Reference Biosphere type models that are intended to be of generic applicability and so, potentially, did not include some key FEPs that are relevant to fennoscandian biosphere systems.

1.2 Review of RCL concepts 2016

With the detailed site descriptive material now available STUK instituted a review of RCL modelling carried out in phases during 2016. The first step (Kłos, 2016a) looked at the alternative interpretations of future biospheres based mainly on the typical landscape objects derived from assessments of the future Forsmark landscape on behalf of SSM (Kłos, 2015ab). Results implied that, modelled as simple systems, with doses calculated for steady-state radionuclide distributions in the modelled biosphere objects, the corresponding release limits would be unnecessarily restrictive.

The second phase of the review (Kłos, 2016b) was used to reconstruct the original dose calculations as

Table 2. Comparison of release scenarios between the 2016 Ruokola's (2002) determination of RCL values. The scenarios are grouped to show corresponding situations. The 2002 derivation used calculated doses at the end of a 10 kyear period. The 2016 review included explicit persistence of the release objects in the landscape. Scenarios for which doses were evaluated in the 2002 modelling but which were not used in the determination of the RCLs are indicated by shading.

2016 Landscape Review			Ruokola (2002) – Doses at 10 kyear	
Release scenario	**variant**	**persistence kyear**	**Release scenario**	**Status at 2002**
Accumulation / Exposure	Wetland → Cultivation	10	Agricultural land	discounted
			Peat Bog	discounted – high doses
Wells	Bedrock wells	1	Garden plot (well)	included
	Overburden Wells	10		
Lake	Small, forest	3	Lake	included
	Medium, forest	8		
	Large, forest	10		
	Small, agriculture	3		
	Medium, agriculture	8		
	Large, agriculture	10		
Rivers	Tributary	10	Running waters	discounted
	Local	10		
	Regional	10		
Coast	Bay	8	Coast	included – low doses
	Open sea	2		

reported by Ruokola (2000) on which the RCLs were based. As with the alternative dose models doses were evaluated using the equilibrium distribution of radionuclides in the modelled ecosystems. These models using the steady-state solution to the compartmental transport matrix were implemented in Excel for simplicity. Implementation of the same models to provide dynamic results (time-varying distribution in the biosphere for an indefinite unit release of radionuclides to the biosphere) showed that in many cases peak doses would arise at times beyond 10 kyear after the start of the release. With these results (Kłos, 2016c) a detailed revise of Posiva's anticipated landscape model development was carried out (Kłos, 2016d) based on data provided by Posiva following a request for additional information (Posiva, 2016).

This review clarified the characteristics of the landscape objects for use in the RCL review, allowing the determination of parameters values and distributions. Details of the models for the objects are given in Appendix A and the derivation of key parameters (with the selected probability distribution functions) is given in Appendix B. Table 2 lists the release scenarios for which the doses have been assessed in the 2002 and 2016 models.

This report builds on the earlier reports (Kłos, 2016abcd) to present a set of recom-mended RCL values for use in future performance assessments. Some further suggestions are given concerning how the RCLs might be interpreted.

Chapter 2 of this report summarises the ecosystems release objects listed in Table 2 with Chapter 3 providing a description of the interpretation of the objects in terms of dose as-sessment models. The derivation of the data used in the probabilistic calculations is discussed in relation to the landscape review. Results are presented and discussed in Chapter 4 and the conclusions and recommendations are in Chapter 5.

2 Ecosystem description for RCL modelling

2.1 Definition of Release Constraint Limits

In Finnish regulations the limiting annual exposure to a small group of the most highly exposed individuals (ie, representative individuals) is D_{lim} = 0.1 mSv year^{-1} (ie, 0.1 / 1000 = 10^{-4} Sv year^{-1}). The radionuclide specific RCL is then determined *as the release rate from the geosphere to the biosphere* that corresponds to this dose level. The release rate is assumed to be constant over time but it is implicit in the Ruokola values that the doses are evaluated at the end of a suitable accumulation period. In the original calculations this was 10 kyear as this was taken to be the time over which conditions in the biosphere would remain broadly constant.

The biosphere models on which the RCLs were based therefore assumed a constant chronic input of 1 Bq year^{-1} and the doses – expressed as Dose Conversion Factors (DCF Sv year^{-1})(Bq year^{-1})$^{-1}$ – for a range of landscape objects are evaluated over the relevant time period. For releases expressed in GBq year^{-1}, the release constraint limit is then expressed as

$$RCL = \frac{D_{lim}}{1000} \cdot \frac{10^{-9}}{\max\left(DCF\right)} \text{ GBq year}^{-1}. \qquad (1)$$

2.2 Overview of landscape object characteristics

The DCFs are calculated for each of the release objects in Table 2. The description of the landscape anticipated at Olkiluoto over the next 10 kyear provides the basic input for the description of the landscape objects in the RCL calculations. The details are interpreted in Kłos (2016d) from the data provided by Posiva (2016).

Figure 1 shows a map of the landscape at 12020 CE based on Posiva's data from the TURVA-2012 assessment (Posiva, 2012a). The density of release points in the map is from the reference case geosphere flow system at 5000 CE. It is not expected that the bedrock flow system would change significantly after this time as the coast would well to the west of this area. The object types identified in Table 2 therefore include some variants that are not present in this map but which are included for completeness (sea ecosystems) or because they should not be ruled out (small lakes). The long-timescale accumulation scenarios are potentially important, however. It should also be remembered that the depiction of the future landscape in Figure 2 is based on Posiva's interpretation of the recently developed site descriptive models and therefore is not necessarily complete or conclusive representation of the future landscape. Nevertheless it is instructive and scopes the set of objects in Table 2 and it also provides the numerical basis for the objects in the RCL calculations, including the data for the landscape objects at earlier times in the Posiva (2016) data release. The Overburden in the region varies in thickness from 0m (bedrock at surface) to around 10 m. In confined areas (small scale depressions in the bedrock surface) there can be even greater thicknesses of Overburden – up to a few tens of metres.

The composition of the Overburden varies considerably and is age dependent. There are the recent post-glacial deposits as well as glacial tills.

The physicochemical properties of the upper Overburden types in Figure 1 therefore vary considerably. The Posiva classification identifies them as

- Bedrock
- Clay
- Mineral soil (coarse, medium, fine)
- Mud / gyttja
- Peat.

These media also embody a range of properties (density, porosity, volumetric moisture content) that influence the transport and accumulation charac-

Figure 1. Posiva (2016) data mapped using Global Mapper 17 (http://www.globalmapper.com/). The map shows the predicted landscape at 12020 CE, illustrating the surface Overburden medium types, the river network and the lakes. For reference the distribution of potential release locations is shown, taken from the TURVA-2012 documentation (Posiva 2012a), shown as the density of calculated release points at 5000 CE (red areas). Coastline at 2020 CE is indicated by the contour line.

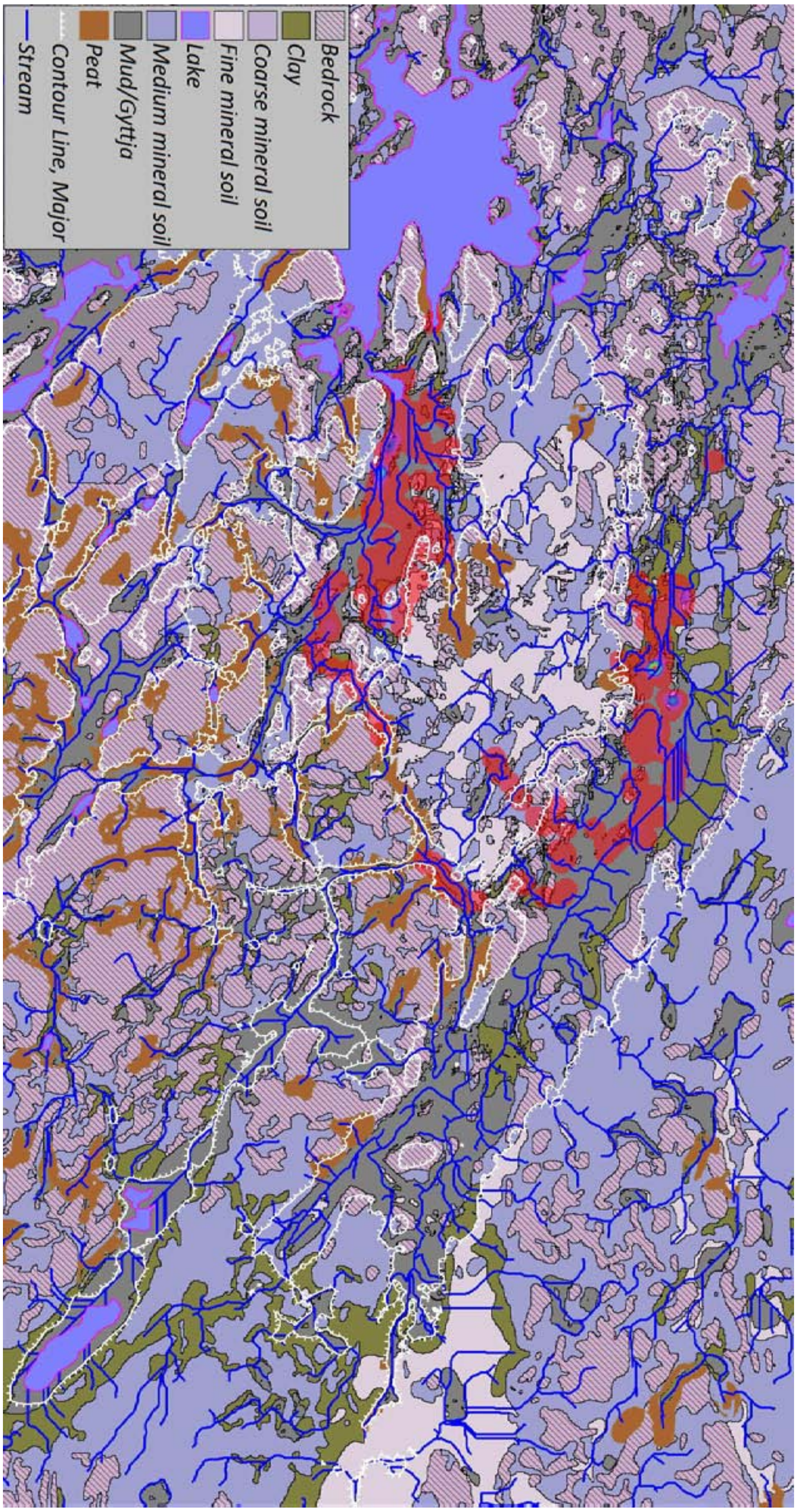
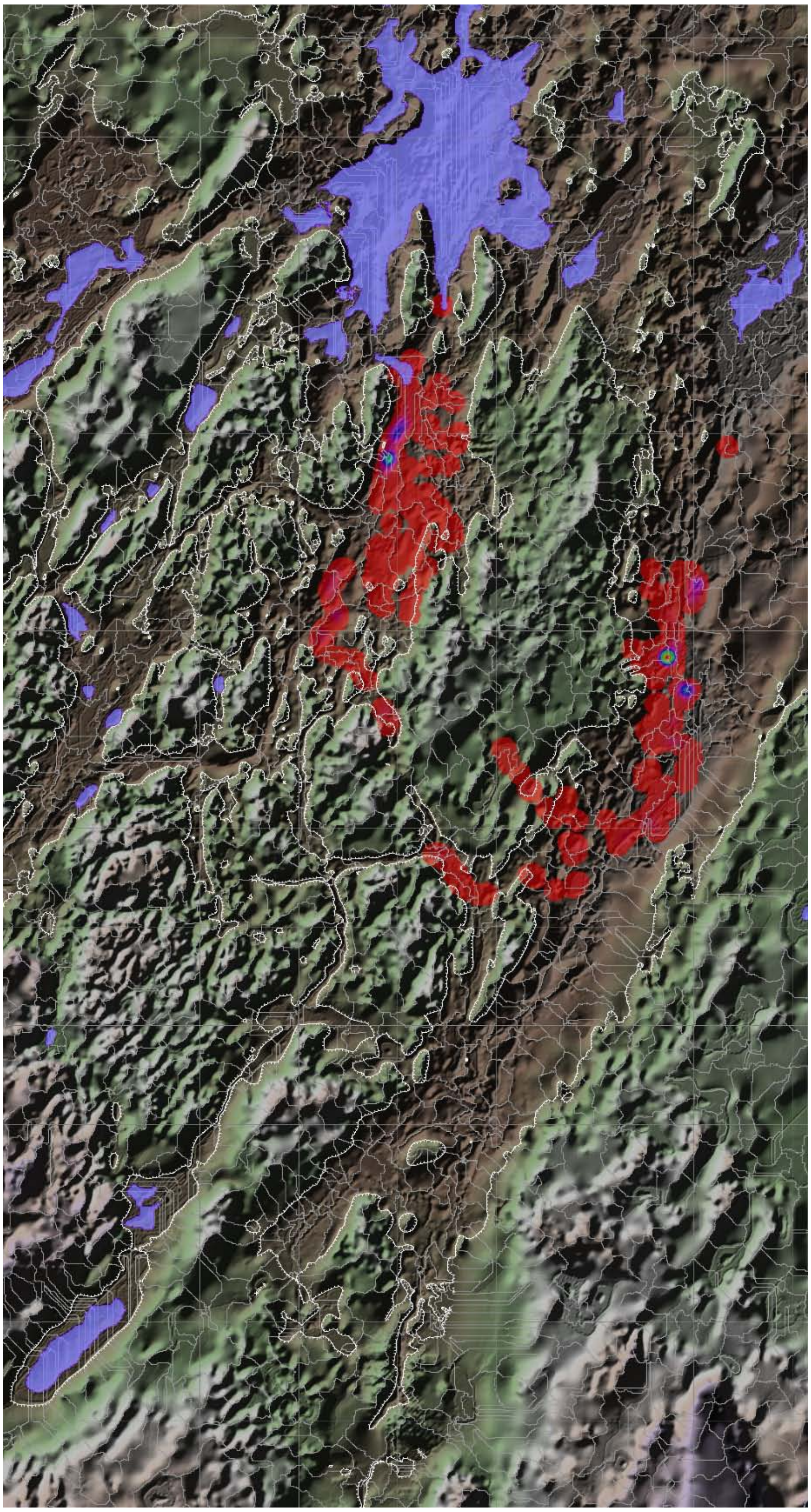


Figure 2. Topographic map of the Posiva (2016) landscape at 12020 CE corresponding to the map shown in Figure 1. Catchment areas (delineated in grey) derived from Global Mapper17 (http://www.globalmapper.com/).



teristics of the landscape objects. As discussed in Section 3 the database for the RCL modelling is based on the most recent publications relevant to regional conditions. In most cases this is the Posiva BSA-2012 biosphere database (Posiva 2014a). More recent are the nuclide data from Tröjbom *et al.* (2013) for the Forsmark site in Sweden. These contain a better differentiation between saturated and unsaturated hydrochemistry as well as a more complete set of radionuclides and so are used. The classification therein is for

- Peat
- Clay/ mineral soils, and
- Mud / gyttja.

This somewhat simplifies the Posiva classification but is believed to be sufficiently representative since details of pdfs and ranges are provided.

Topography determines a number of important characteristics that are relevant of to the dose assessment models. The topographic datasets in the Posiva (2016) data release allow the mapping of watersheds and the potential surface drainage system. These data can be used to identify suitable catchment areas that, in turn, define the basic units of the surface system into which radionuclides can be diluted. Combined with the climate data these are used to define the water balance that drives radionuclide transport and accumulation in the RCL models.

These are the features of the surface environment that are the focus of the RCL model. They allow a region- and site specific description of transport and accumulation. To determine the doses to the local human population requires the identification of habits and lifestyles that lead to exposure. The selection of data for the RCL modelling focusses on the characteristics of the site. The parameters describing exposure used the behaviour of the current Finnish population as a suitable yardstick by which to gauge the potential radiological impact on future populations. This means that consumption data provided by surveys of the Finnish population in Posiva (2012c) are assumed to give a practical estimate of the habits and practices of the exposed population. Correspondingly this includes agricultural and cultivation characteristics of the population, including the properties of relevant flora and fauna.

3 Models and data

3.1 Models for release objects

Between the Ruokola (2000) landscape object models and those used in the 2016 review there are numerous differences of interpretation. As noted by Kłos (2016b) there were more exposure pathways in the original calculations but many of these are no longer included as they did not contribute significantly to the overall dose. One such is the combustion of contaminated peat, another describes doses from the consumption of foodstuffs from the shorelines of bays.

The focus is on the transfer of radionuclides in solution – water balance for the modelled systems is the major determinant of dose. Transport on solid material is of lesser importance or is implicit in the assumptions of rapid internal mixing within the spatial volumes of the compartments defined. Bioturbation does not act to transfer particulates between soil layers since most biological activity takes place in the unsaturated zone. It is therefore responsible for mixing within the upper soil zone. On the other hand, sedimentation is an important feature of the model and this solid mediated transfer is explicitly included.

The most significant difference between the 2000 models and the 2016 models is the inclusion of a specific compartment representing the lower Overburden. In 2000, for the initial model descriptions, the biosphere was taken to comprise water bodies (water and sediment) and soils, including a rooting zone for flora and a deeper intermediate zone. Release of activity was to either sediment or the lower soil layer. The review of the Posiva (2016) data release in Kłos (2016d) showed that the overall thickness of the Overburden in the parts of the system where releases are likely could vary by an order of magnitude. One of the reasons for the high DCFs calculated (but not used) by Ruokola (2000) can be traced to the release being to the upper parts of the regolith, effectively by-passing potentially important thicknesses of Overburden material.

To omit the material between the “geosphere” (bedrock) and “biosphere” (soil layers) is conservative but, in the light of the results from Ruokola (2000) as reproduced by Kłos (2016c), the degree of conservatism can be seen as being too restrictive. For this reason the lower Overburden layer has been introduced into the models here. This approach is still conservative in that a single compartment is assumed for the lower Overburden. Because the compartment model approach adopted here assumes effectively instantaneous mixing in the compartment, this means that the transfers to the soil layers or bed sediments of water bodies is more rapid than might be expected in reality. This affects strongly sorbing radionuclides the most so that the doses obtained will be higher (potentially reaching their steady-state values) earlier in the simulation.

Models for the RCL evaluation have been implemented in Ecolego[1]. The Ecolego interaction matrices for the models are briefly described in Appendix A, below. The models themselves are available and may therefore be considered as part of the documentation of the project. All FEP descriptions employed in the models may be found therein. The accumulation/exposure model has been reinterpreted so as to be able to function correctly in the probabilistic analysis carried out here. The new details are set out in Appendix A.

The following “rules” are applied when evaluating doses from each object type:

1. Dose for each model type is calculated with respect to the *persistence* of the object in the landscape
   a. For the *bedrock well* the dilution is determined by the Q_{dil} parameter – there is no accumulation in the well as $k_d = 0$ is assumed
   b. Dose at 10 kyear is calculated for *overburden wells* – this allows for accumulation of high k_d nuclides in the till that is assumed to be the base material of the wells

1 http://ecolego.facilia.se/ecolego/show/HomePage

Table 3. Characteristics of landscape objects for RCL modelling with ranges based on an interpretation of the Posiva (2016) data release. Modified from Kłos (2016d).

	area m²		mean depth m		persistence kyear	Overburden thickness m		
release object	lower	upper	lower	upper		lower	upper	type
small lake	5.0E+03	3.0E+05	0.3	1.5	~2.5	1	6	peat, mud/gyttja, clay
medium lake	1.0E+05	1.0E+06	1	2	2 to > 8	2	5	peat, mud/gyttja, clay
Large lake	1.0E+06	5.0E+06	2	5	> 8	2	10	peat, mud/gyttja, clay
Open Sea	5.0E+05	5.0E+06	2	8	2	0	6	all types
Bay	1.0E+04	5.0E+05	1	2	~3	0	6	all types

	sub-catchment area m²		Overburden thickness m		
release object	lower	upper	lower	upper	type
Regional river	multiple		0.5	6	all types
Local rivers	multiple		0.5	6	All types
Tributary river	5.0E+03	5.0E+05	0.5	6	all types
Wetland	5.0E+03	5.0E+05	0.5	6	peat, mud/gyttja, clay
Forest	5.0E+03	5.0E+05	0.5	6	mineral soils
Agricultural land	5.0E+03	5.0E+05	0.5	6	all (not bedrock)

c. For all objects other than the bedrock well, dilution is determined by the overall accumulation of net precipitation in the local and upstream catchments.

2. Statistics are calculated for arithmetic mean and standard deviation, and geometric mean, as well as 5th and 95th percentiles and median. These define the basic results for the uncertainty study.

3.2 Database

3.2.1 Site characteristics

The site-characteristic database for the 2016 review are as set out in Kłos (2016a) and Kłos (2016c). Data for these final calculations are, however, probabilistic and data describing the distributions of parameters are taken from the Posiva (2014a) database but the characteristics of the landscape objects are defined with reference to the analysis of the landscape in the Posiva (2016) data release. Table 3 summarises the agricultural land from Kłos (2016d). This is the basis for the interpretation of the statistical representation of objects and is used as guidance for the interpretation of characteristics in this probabilistic analysis.

The numerical values for the RCL evaluation are listed in Appendix B. This includes the data taken from Posiva (2014a) as well as the landscape data derived from the analysis of the DEM (digital elevation map) information provided by the maps in the POSIVA (2016) data response. The methods used to obtain these values are outlined below.

3.2.2 Catchment areas, rivers and lakes

Statistical analysis of the landscape in the period beyond 10 kyear AP uses the 12020 CE DEM map on the basis that the release locations for the Onkalo deep geological repository are reasonably represented by the TURVA-2012 results and that the landscape beyond 12020 CE is reasonably well represented by the 12020 CE landscape model. Any releases from a LILW repository on Olkiluoto Island would be expected to occur closer to the present-day coastline. From the map shown in Figure 3 the areas of catchments for the landscape can be determined. The TURVA-2012 release map indicates specific areas for potential releases. However, these are closely linked to the depth of the repository and to the selected model of the discrete fracture network chosen. Catchments from the entire landscape are

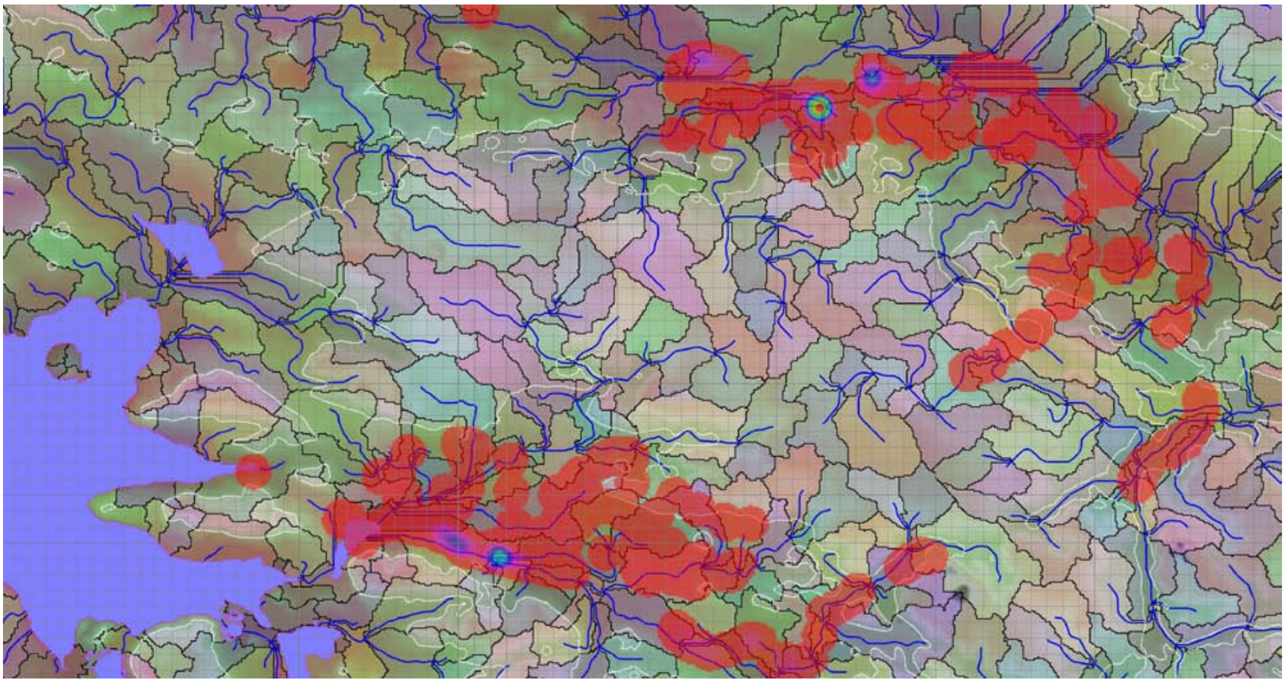


Figure 3. Lakes, streams and catchments in the 12020 CE DEM. Areas identified by Global Mapper 17 using the DEM are analysed to derive the pdf shown in Figure 4. Turva-2012 release point density shown for illustration.

used so as to allow for the analysis to be suitable for disposal at different depths in the bedrock.

The size of catchments determines how much accumulated surface water flows through a system. The distribution of catchment area size is therefore useful to determine sizes of objects. Excluding the catchment areas under the large flat lake areas, the areas are computed. There are 338 catchments identified in the landscape and these are used to generate a log-normal distribution for catchment areas. This excludes the 49 areas identified as having areas of 100.17 m² – this seems to be an artefact of the GM17 software. Such areas are therefore not used as they are far too small to be used for cultivation in the dose model.

Translation into Ecolego requires the distribution to be codified in some way. The sample size is relatively low so rather than use the raw data a log-normal has been used that captures the range, width and geometric mean. By eye, the fit is reasonable (Figure 4). There are some points to note. The log-normal does not represent the excess of small catchments ($A_{catch} \lesssim 2.5\times10^{-4}\,m^2$) and similarly there are slightly more catchments with areas 2×10^5 and 3×10^5 m². Given the uncertainties inherent in the

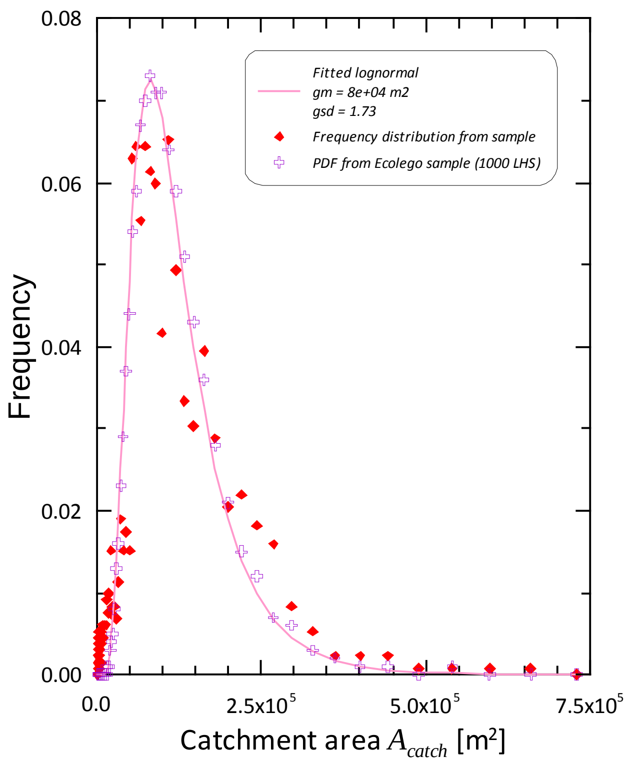


Figure 4. Distribution of size of catchments areas in Figure 3. A log-normal pdf has been estimated to represent the variation. Also shown is the sample set produced by Ecolego's LHS sampling.

modelling, it is assumed that these minor discrepancies are insignificant in terms of determining the RCL values.

A similar analysis has been applied to the length of streams and the corresponding aquatic areas. The analysis here has identified the size of catchments adjoining streams and derived the log-normal distribution to represent them. In Figure 5 the locations of streams identified for the topographic map suggests that there are 128 streams in “autogenic catchments”. These are the areas from which the drainage system arises, with no further upstream catchment. This dataset defines the river classification: *Tributary Rivers*. The maximum water flow is defined by the net precipitation accumulated in the catchment.

Figure 5 shows a composite map of the area looking towards Olkiluoto island from the southeast. In this present-day rendering there is sea to the north and south of the island. Inflow to the northern sea area comes from two regional rivers, the *Eurajoki* and *Lapinjoki*. For this reason, there are two types of river model that include throughflow as part of the overall drainage system.

Inflow to the northern sea area comes from two regional rivers, the *Eurajoki* and *Lapinjoki*. For modelling purposes it is therefore assumed that the overall inland catchment for this part of the regional drainage system would not change and so is kept constant and not sampled. This corresponds to the *regional river* interpretation.

The southern area has a flow system defined by the *local river* catchments only. For this model the issue is how many catchments contribute to the through flow in the river water. This is the basis for the analysis illustrated in Appendix B.

The model for medium and large lakes uses a similar interpretation to that in the river models. The treatment of the lower Overburden is the same although the areas differ – lakes are larger than rivers. The analysis of the terrestrial catchments around lakes takes into account the catchments that border the lakes. The impact of upstream catchments is similar to that in the river models.

Figure 5. Location of regional rivers in the present-day landscape. Combined 3D landscape model with Google Earth imagery. Note that there are areas of cultivated land along the Lapinjoki that are currently below sea level in the Posiva landscape model (as indicated by the white coastline in the image.

3.2.3 Marine models

Although it is unlikely that releases to marine objects will be important in the period beyond 10 kyear AP the cases of release to bays and open water are also evaluated. The present day landscape is used to identify characteristics of bays, as shown in Figure 6. Bays are modelled as exchanging water with the outer sea area and also receiving input from terrestrial catchments. The open sea model simply has a water exchange with adjacent sea areas. For sea areas only a single type of material is assumed for the marine sediment compartment, namely k_d*_rego_aqu* from the SR-PSU database (Tröjbom *et al.*, 2013, see following section). Appendix B outlines how the data are interpreted for these models.

3.2.4 Nuclide-specific data

As set out in Kłos (2016a) the most recent compilation of radionuclide specific data that has close relevance for Finnish conditions is that produced by Tröjbom *et al.* (2013) for the SR-PSU assessment carried out for a low and intermediate level waste repository at Forsmark, Sweden.

From Tröjbom *et al.* (2013) the alternative media properties are as follows:

- Anaerobic till – k_d*_regoLow* (m^3/kg dw).
- Anaerobic glacial clays – k_d_regoGL (m^3/kg dw).
- Water saturated anaerobic deposits (clay gyttja and gyttja) – k_d*_regoPG* (m^3/kg dw).
- Anoxic, water saturated organic sediment in wetland/peatland ecosystems – k_d*_regoPeat* (m^3/kg dw).
- Well drained clayey till – not in contact with ground water, high soil biological activity and corresponding high rate of mineralisation – k_d*_regoUp_garden* (m^3/kg dw).
- Soil of organic origin (peat and postglacial sediments of aquatic origin) and drained through ditching. This means more oxic conditions – k_d*_regoUp_drain* (m^3/kg dw).
- Upper oxic layer of terrestrial regolith (peat) – k_d*_regoUp_ter* (m^3/kg dw).
- The aquatic upper regolith compartment represents the upper layer of aquatic regolith (Saetre *et al.* 2013). In the Baltic Sea, these sediments are aerobic, biologically active and approximately 0.10 m deep. In lakes and streams this layer is about 0.05 m deep (Håkanson *et al.* 2004, Andersson, 2010) – k_d*_regoUp_aqu* (m^3/kg dw).

Each of the models can in principle be configured for each combination of surface media. The combinations selected in the RCL determination are set out in Table 4. The numerical values used are given in Appendix C.

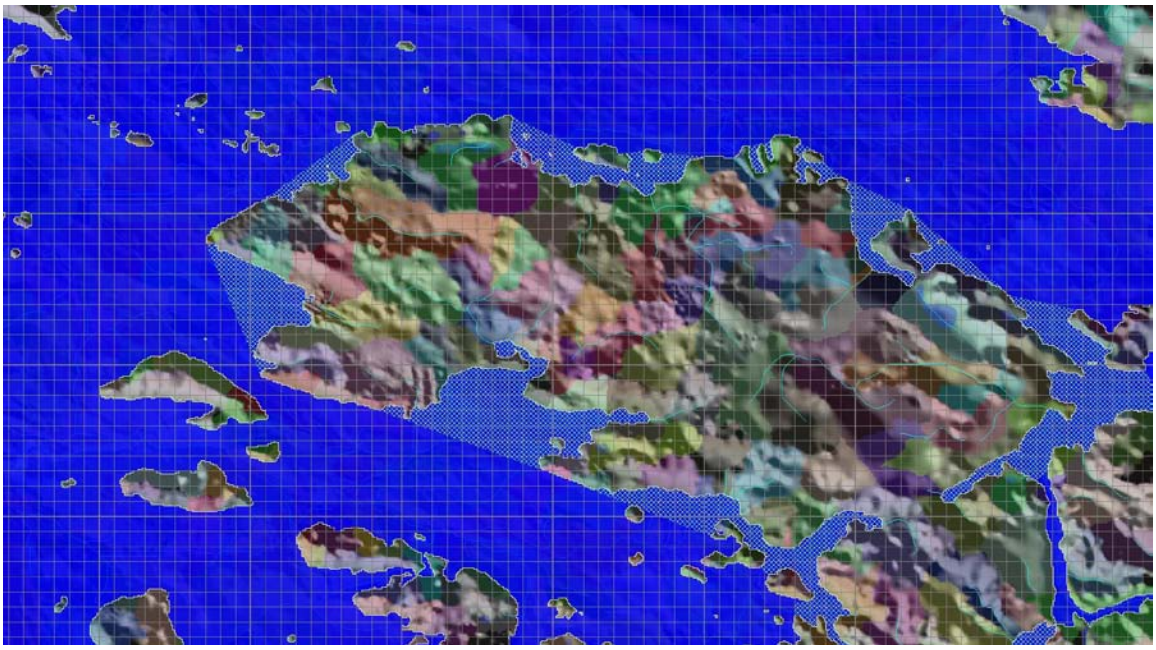


Figure 6. Interpretation of bay areas based on the Olkiluoto present day DEM (2020 CE). Local terrestrial catchments are as-sessed and the extent of the bays relative to open water are indicated by the shaded marine areas.

Table 4. Overburden media combinations for the calculations. In all cases the material of the lower Overburden is till. Upper regolith – comprising deep soil and top soil (terrestrial) and bed sediment (aquatic) – are paired according to the classification shown (peat, mineral–clay and mud–gyttja.

model	OB media	LOB (till)	deep soil	top soil	bed sediment
Bedrock well	peat	–	KD_regoPeat	KD_regoUp_ter	–
(at 1 year)	mineral–clay	–	KD_regoGL	KD_regoUP_garden	–
	mud–gyttja	–	KD_regoPG	KD_regoUP_drain	–
Overburden well	peat	KD_regolLow	KD_regoPeat	KD_regoUp_ter	–
(at 10 kyear)	mineral–clay	KD_regolLow	KD_regoGL	KD_regoUP_garden	–
	mud–gyttja	KD_regolLow	KD_regoPG	KD_regoUP_drain	–
Rivers	peat	KD_regolLow	KD_regoPeat	KD_regoUp_ter	KD_regoPeat
(all at 10 kyear)	mineral–clay	KD_regolLow	KD_regoGL	KD_regoUP_garden	KD_regoGL
	mud–gyttja	KD_regolLow	KD_regoPG	KD_regoUP_drain	KD_regoPG
Lakes (small)	peat	KD_regolLow	KD_regoPeat	KD_regoUp_ter	KD_regoPeat
(at 3 kyear)	mineral–clay	KD_regolLow	KD_regoGL	KD_regoUP_garden	KD_regoGL
	mud–gyttja	KD_regolLow	KD_regoPG	KD_regoUP_drain	KD_regoPG
Lakes	peat	KD_regolLow	KD_regoPeat	KD_regoUp_ter	KD_RegoPG
medium (8 kyear)	mineral–clay	KD_regolLow	KD_regoGL	KD_regoUP_garden	KD_regoGL
large (at 10 kyear)	mud–gyttja	KD_regolLow	KD_regoPG	KD_regoUP_drain	KD_regoPG
Open Sea (at 2 kyear)	mineral sediments	KD_regolLow	–	–	KD_regoAqu
Bay (at 3 kyear)		KD_regolLow	–	–	KD_regoAqu
Accumulation / Exposure	peat	KD_regolLow	KD_regoPeat	If (time < 10000.0, KD_regoPeat, KD_ regoUp_ter)	–
Accumulation over 10 kyear, dose over next 50 year	mineral–clay	KD_regolLow	KD_regoGL	If (time < 10000.0, KD_regoGL, KD_ regoUp_garden)	–
	mud–gyttja	KD_regolLow	KD_regoPG	If (time < 10000.0, KD_regoPG, KD_ regoUp_drain)	–

3.2.5 Other data

The datasets reproduced here are included because they give the pdfs and other information in respect of the statistics of the dataset. Numerical values for non-sampled parameters are found in the earlier reports (Kłos, 2016acd).

4 Results and discussion

4.1 Dose conversion factors and recommended release constraint limits

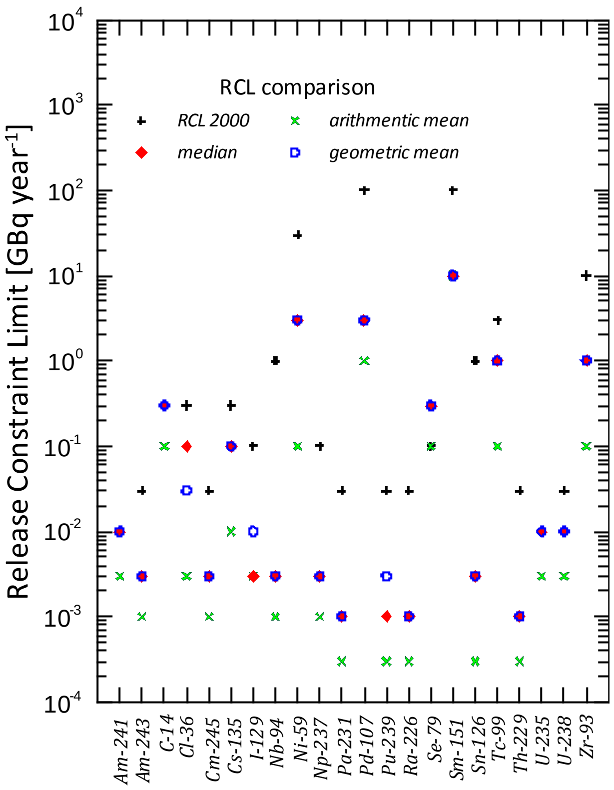
The models described in the previous section have been implemented in Ecolego and statistical analysis carried out using the inbuilt routines. 1000 Latin Hyper-Cube samples were used. The RCLs were obtained from the calculated Dose Conversion Factors (DCFs – total dose over all pathways for unit constant release) for each of the landscape objects and media types shown in Table 4 using Equation (1). The DCFs for each of the 19 variants for each of the radionuclides are shown in Appendix D, colour coded to illustrate the objects giving the highest doses (corresponding to the lowest RCLs).

For each radionuclide then, the RCL is the lowest for each of the 19 variants. The recommended RCL values from the calculations are shown in Table 5. Three sets of derived values for the RCL are shown based on different statistics – median, arithmetic mean (AM) and geometric mean (GM). The statistics are not used directly, as with the Ruokola results the numerical values are rounded to either 1×10^{n} or 3×10^{n}. The values are plotted in

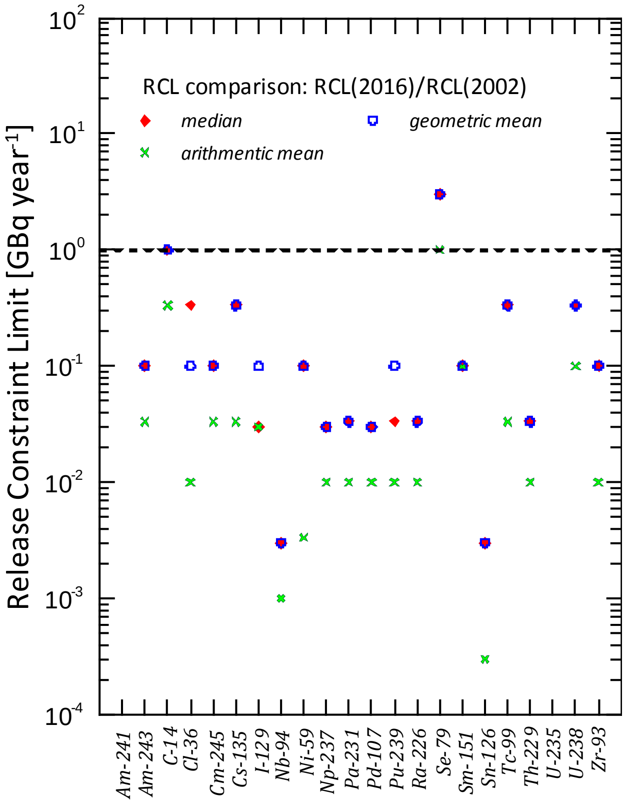
Table 5. Suggested RCLs from the 2016 analysis compared to the current values.

	RCL 2016			
nuclide	RCL (AM)	RCL (median)	RCL (GM)	RCL 2002
Am-241	0.003	0.01	0.01	
Am-243	0.001	0.003	0.003	0.03
C-14	0.1	0.3	0.3	0.3
Cl-36	0.003	0.1	0.03	0.3
Cm-245	0.001	0.003	0.003	0.03
Cs-135	0.01	0.1	0.1	0.3
I-129	0.003	0.003	0.01	0.1
Nb-94	0.001	0.003	0.003	1
Ni-59	0.1	3	3	30
Np-237	0.001	0.003	0.003	0.1
Pa-231	0.0003	0.001	0.001	0.03
Pd-107	1	3	3	100
Pu-239	0.0003	0.001	0.003	0.03
Ra-226	0.0003	0.001	0.001	0.03
Se-79	0.1	0.3	0.3	0.1
Sm-151	10	10	10	100
Sn-126	0.0003	0.003	0.003	1
Tc-99	0.1	1	1	3
Th-229	0.0003	0.001	0.001	0.03
U-235	0.003	0.01	0.01	
U-238	0.003	0.01	0.01	0.03
Zr-93	0.1	1	1	10

Figure 7. Results for Release Constraint Limits. Results for arithmetic mean, median and geometric mean from the uncertainty analysis on the revised landscape models.



(a) Derived RCL values from the maximum dose conversion factors for each landscape object



(b) RCLs normalised to the current values (Ruokola, 2002)

Figure 7(a) in absolute terms, showing the numerical results in comparison to the Ruokola (2002) values. To illustrate how the 2016 results have changed, the new values are plotted normalised to the Ruokola (2002) values in Figure 7(b). The normalised plots illustrate how the revised RCLs are all lower than the current values (with the exception of ^{14}C, ^{135}Cs, ^{79}Se and ^{99}Tc, depending on which statistic is selected).

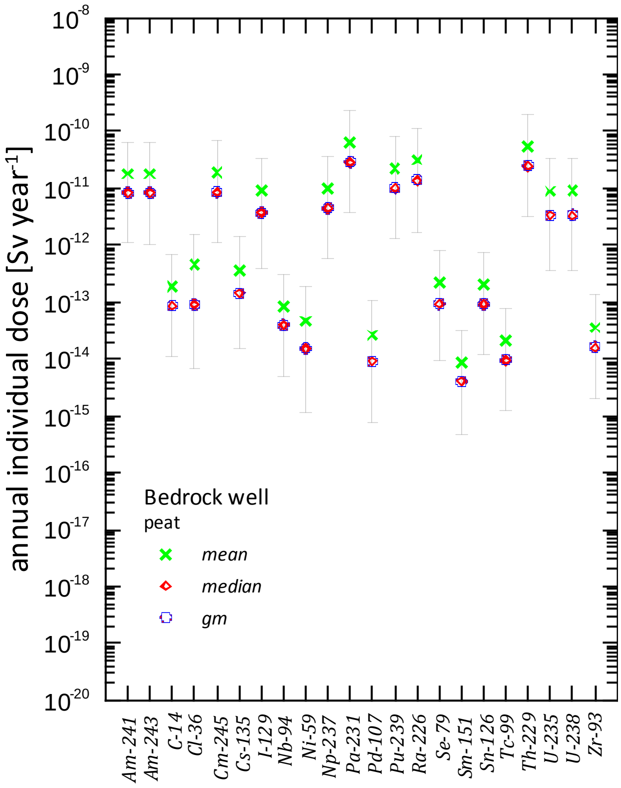
Mean and median values are similar most cases (see Section 4.4 below). For these statistics most radionuclides have RCLs that are now up to a factor of ten more restrictive (18 out of 22) and only two are more than a factor of ten more restrictive (^{94}Nb and ^{126}Sn). In one case, the new RCL is three times higher than the old value (^{79}Se). The mean values are still more restrictive – six are a factor of ten lower and a further eight are around 30 times lower. Four (^{93}Zr, ^{36}Cl, ^{94}Nb and ^{126}Sn) are between 100 and 300 times more restrictive. Only ^{14}C and ^{79}Se have the same as the old values.

The results for DCF in Appendix D also identify the more important landscape object types in the derivation of the RCLs. Both mean and median results show that the most significant objects are the wells and the accumulation/exposure scenario (based on accumulation in a small lake that becomes a wetland). The RCLs are the values derived from the highest of these DCFs.

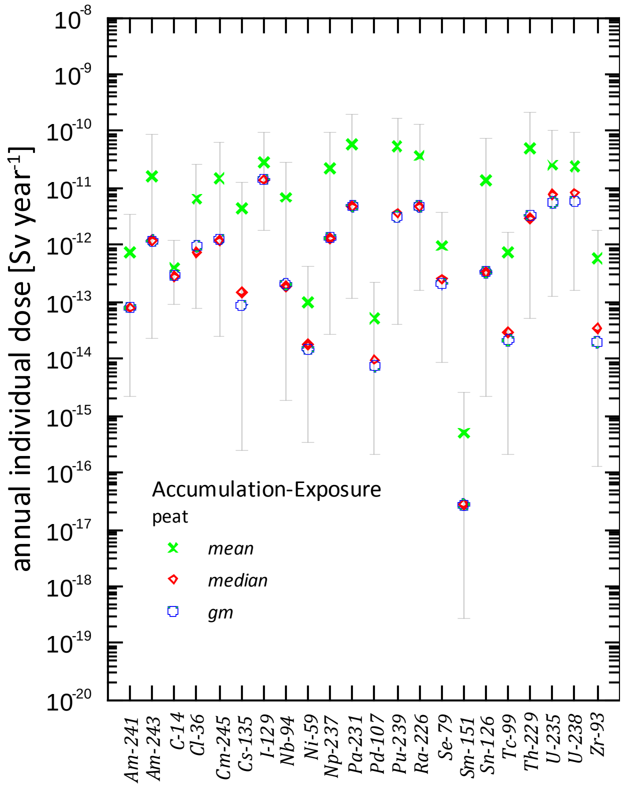
4.2 Uncertainty analysis

As discussed in Appendix D, only the well and accumulation/exposure scenarios are important for the derivation of RCLs. Results from these and, because of the potential importance of ^{14}C in safety assessments, the tributary river objects, are considered in greater detail in respect of the range of values. Figure 8 shows results for selected objects and indicates the range from the 5th to the 95th percentile in the probabilistic results. Peat is used to illustrate results from the well and accumulation/exposure cases and the tributary river case is for the mud–gyttja k_d dataset.

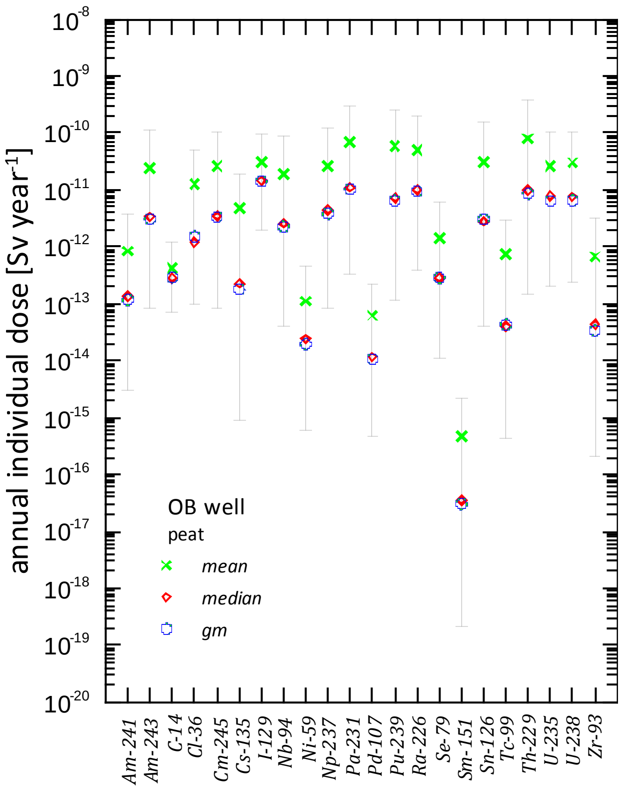
The bedrock well case (a) has the narrowest range, indicating that there are only a small number of parameters contributing to the uncertainty. It shows two distinct groups of radionuclides – those with DCFs around 10^{-11} Sv Bq^{-1} and those for which the values are between 10^{-14} and 10^{-12} Sv Bq^{-1}. This pattern is repeated for the other cases shown here,



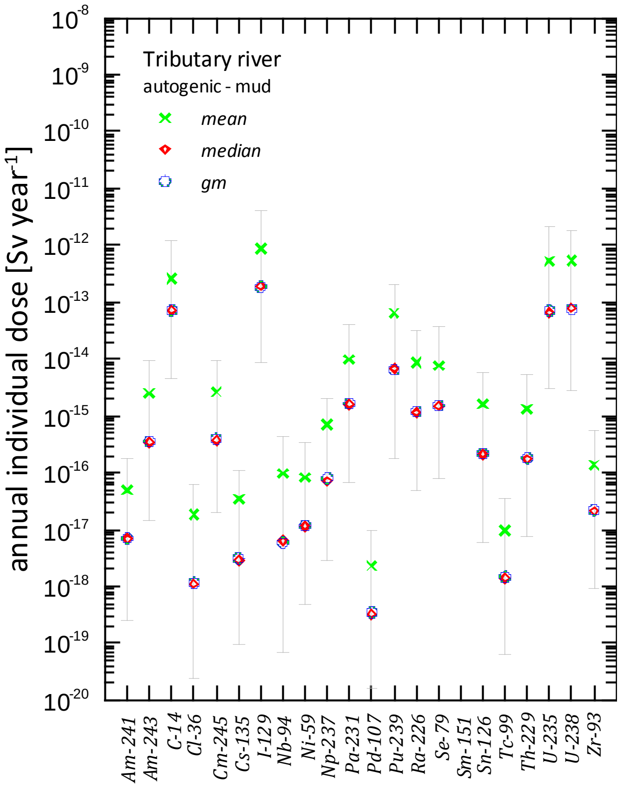
(a) Bedrock well (peat)



(b) Accumulation / Exposure (peat)



(c) Overburden well (peat)



(d) Tributary river (mud/gyttja)

Figure 8. Ranges of results from selected landscape objects showing arithmetic mean, median, geometric mean and 5th and 95th percentiles.

though it is less obvious, taking the ranges from the other objects into account.

Results from the accumulation/exposure case and the Overburden well case are broadly similar since they both allow for long term accumulation (doses calculated at the end of a 10 kyear accumulation period). This assumption probably overestimates the risk from the Overburden well since the model employs irrigation which is unrealistic over an extended period. Nevertheless, the accumulation in the Overburden of the lake-wetland combination that is assumed drained for the exposure scenario in case (b) is realistic. Doses in this case are slightly higher than in case (c) for the Overburden well. This indicates that it is retention of radionuclides in the regolith that is important for determining dose, the lower Overburden acting as a reservoir for radionuclides.

The ranges for both the Overburden well and the accumulation/exposure scenarios are wide – typically four orders of magnitude – this is associated with the characteristics of the lower Overburden which is not present in the Bedrock well case.

Doses from the tributary river case are shown since the results for ^{14}C are comparatively high compared to the well and accumulation/exposure scenarios. ^{14}C has a small 90% range in those cases but it is larger in the tributary river case. Results from ^{129}I are also relatively high compared to the other radionuclides. River dilution is the most likely cause.

4.3 Sensitivity analysis

The sensitivity analysis carried out here looks in greater detail at a selection of radionuclides from the overall ensemble. These are:

- ^{36}Cl (mobile radionuclides in the Overburden)
- ^{59}Ni (important radionuclide in TURVA-2012)
- ^{126}Sn (strongly sorbing γ-emitter, important in TURVA-2012)
- ^{129}I (relatively mobile radionuclide, long-lived)
- ^{135}Cs (important radionuclide in TURVA-2012)
- ^{226}Ra (release peaks beyond 10 kyear in TURVA-2012, α-emitter)
- ^{14}C (special case radionuclide).

Results from the two well scenarios and the accumulation/exposure objects are considered since these are the most important landscape objects for dose as discussed in Section 4.1. Results for the tributary river object are also included because of the potential relevance to the model for ^{14}C implemented here.

Full results for the seven radionuclides in the four landscape object models are given in Appendix E. The chosen statistic is the Standardised Rank Regression Coefficient. This has been applied to the total dose over all pathways. The table of calculated SRRCs in Appendix E gives the top ten contributing parameters in each case. To further illustrate the results of the sensitivity analysis tornado plots for ^{36}Cl (weakly sorbing in the Overburden media) and ^{226}Ra (strongly sorbing) are shown in Figure 9 and Figure 10 respectively.

The relatively narrow uncertainty bounds in Figure 8 for the bedrock well models is readily explained – the SRRC values for Q_{dil}, the dilution parameter for the well, are close to –0.9 in all cases so that dilution dominates all other parameters. Only for ^{36}Cl and ^{59}Ni are the SRRCs for dilution less than 0.9. For these radionuclides the pasture root uptake parameter, transfer factor for milk (^{36}Cl) and the transfer factor for meat (^{59}Ni) have a significant influence on the range of doses. Transfer factors to milk for ^{129}I and ^{135}Cs have a minor influence. In Appendix E the cut-off for significance in the SRRC values is taken to be ±0.1. For the strongest sorbing radionuclides (^{126}Sn , ^{226}Ra) no other parameters are significant. This analysis suggests that a more suitable value might be ±0.25 for purposes of determining impact on DCFs.

Dilution is also important for the other landscape object models though it is expressed differently. For terrestrial models (Overburden well and accumulation/exposure) dilution is given by the net precipitation and the catchment area. Similar considerations also apply to the river models. For the weakly sorbing ^{36}Cl in Figure 9 the most important parameter is the soil kd in the upper regolith soil. This is positively correlated since it acts to retain radionuclides in the soils from which dose is derived. Similarly the pasture uptake parameter is correlated to higher concentrations in pasture (thereby meat and milk).

For the less strongly sorbing radionuclides transport through the lower Overburden is relatively rapid. The area parameters are negatively correlated since larger areas mean higher dilution in the Overburden within the objects. The higher the k_d values in the Overburden, the more important

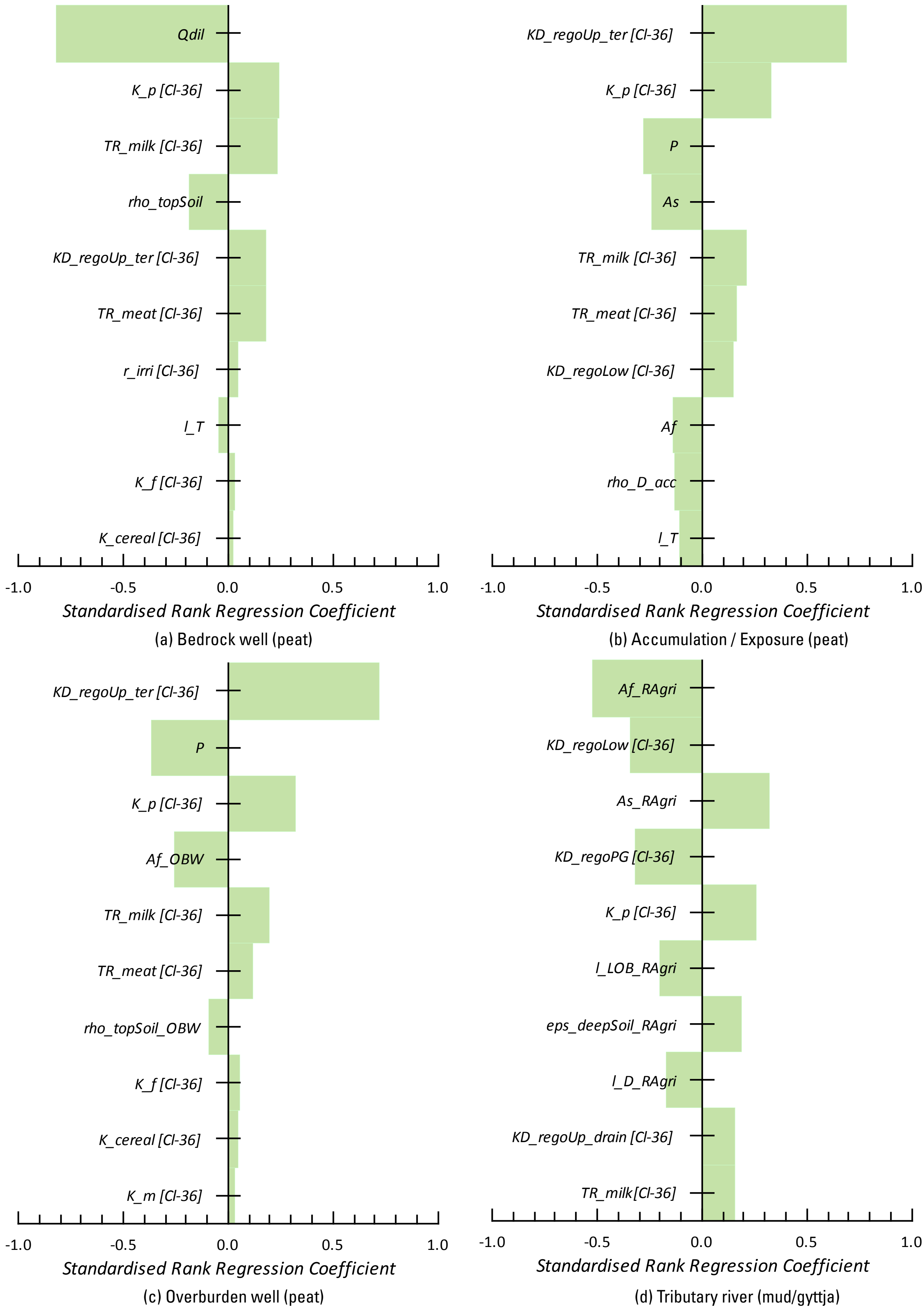


Figure 9. Parameters contributing to uncertainty in the DCF for ^{36}Cl (weakly sorbing in Overburden).

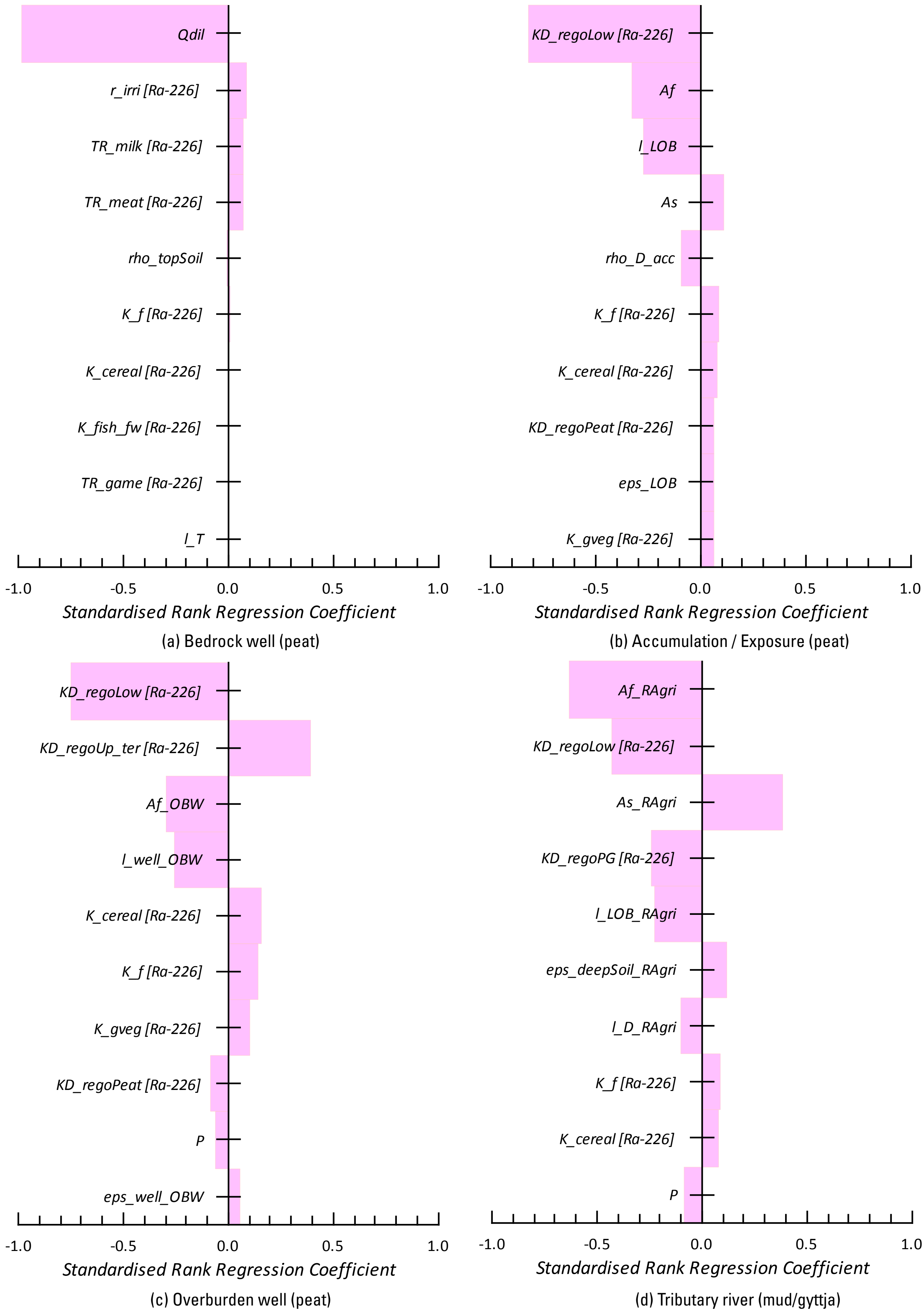


Figure 10. Parameters contributing to uncertainty in the DCF for ^{226}Ra (strongly sorbing in Overburden).

is the representation of the lower Overburden. In Figure 10, for ^{226}Ra, the lower Overburden k_d is the most significant parameter. Similarly the area and *thickness* (combining to give the volumetric dilution in the lower Overburden) are also indicated as important (parameters *Af*, *l_LOB* for the accumulation/exposure model and *Af_OBW* and *l_well_OBW* in the Overburden well model). Appendix E shows similar patterns for the other moderate to high sorbing species in the landscape models.

The representation of ^{14}C in the modelling here emphasises the need to review the model for ^{14}C. In the results shown in Appendix E, the set of parameters important for ^{14}C differ somewhat compared to those for the other radionuclides, other than the dilution parameters in the bedrock well model. Parameters implicated in the dilution are important in each of the models. Parameters in the calculation of exposure (in contrast to those used to determine environmental concentrations) are positively correlated. One parameter in the tributary river model that is also positively correlated across each of the radionuclides is the area of the river (parameter *As*).

As formulated these relatively simple models are intended to be robust. The database does not include interparameter correlations, Relations between parameters are implemented by fixed deterministic relationships: the media hydrogeochemistry are evaluated for specific combinations based on the OB maps (see Figure 1). In principle a correlation between the properties of the mid- and upper OB layers is likely but the results here have not taken this into account. To test the implications an additional set of results has been run for the accumulation-exposure scenario, peat soils. This is because this scenario gives some of the highest calculated DCFs but also, since the scenario combines different areas in the same calculation there is more scope for correlation. Appendix F gives further details together with a review of the results.

In practice there is little impact on the results. The main influence is on the width of the distribution. From this it is concluded that the models are robustly implemented with respect to the parameter sets.

4.4 Statistic for defining RCL

The RCL provides a single numerical value by which to compare the calculated release from the bedrock. STUK (2013) uses the phrase *the average long-term quantities of radioactive materials released into the living environment from disposed nuclear waste.* The question is: which average?

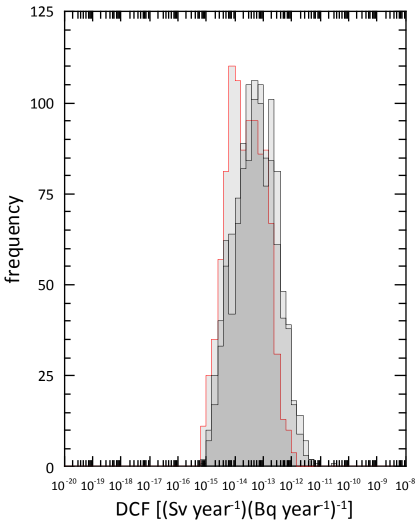
Figure 7 shows that there are clear differences between the arithmetic mean and the geometric mean, which is often close to the median value. Furthermore the range of calculated doses, shown as the interval between the 5th and 95th percentiles in Figure 8, can be several order of magnitudes. There is clearly considerable uncertainty in the calculations. In part this comes from the simplifications required to define the landscape objects modelled here. The mismatch between the arithmetic and geometric means is due to the many logarithmically distributed input variables.

Figure 11 shows the distributions of ^{59}Ni (symmetric in log-space) and ^{36}Cl (asymmetric). The plots are shown for each landscape object type that were identified as being important and each superimposes the distributions for the three Overburden media types. The more symmetric the distribution the closer are the median and geometric mean values. The arithmetic means are controlled by the sample sets for which the doses are relatively high. As these are therefore more restrictive in the derivation of the RCL values, the arithmetic means are used in the calculation.

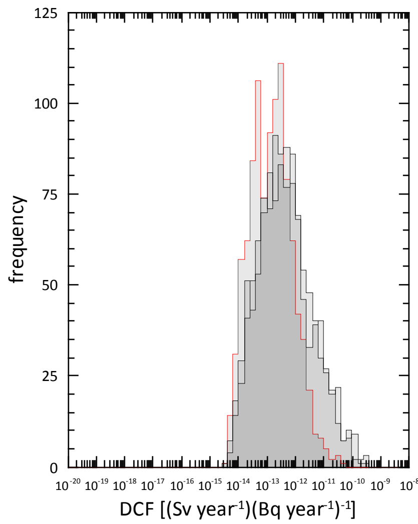
Each of the statistics has useful features but, alone, none can express the *range* of uncertainty. As there is considerable uncertainty associated with the range of results the preferred quantity is the **arithmetic mean** since is the most conservative of the three measures of the “average”. However, the precedent established by Ruokola (2002), whereby the specified RCL values are simplified to one significant figure and round to 1×10^n of 3×10^n means that there is not as much of a difference as there might have been.

A final point to note in the context of Figure 11 is that there is considerable overlap between the distributions for the different media types for the landscape objects shown. This suggests that it may not be necessary to distinguish between the chemistry of the different soil types. Notably, the results for the bedrock well case with peat soils shown that there can be some differences so that question is not settled.

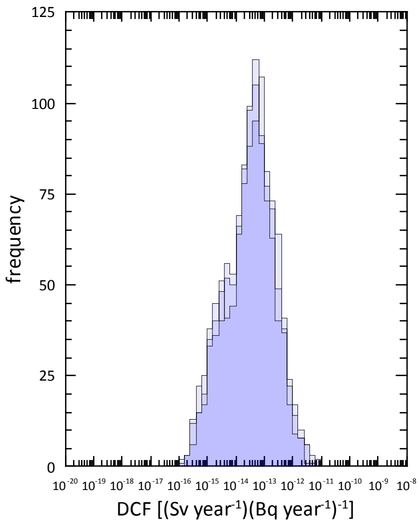
It should also be recognised, however, that k_d dataset used here is not the most suitable for the Overburden geology at Olkiluoto. It is based on the



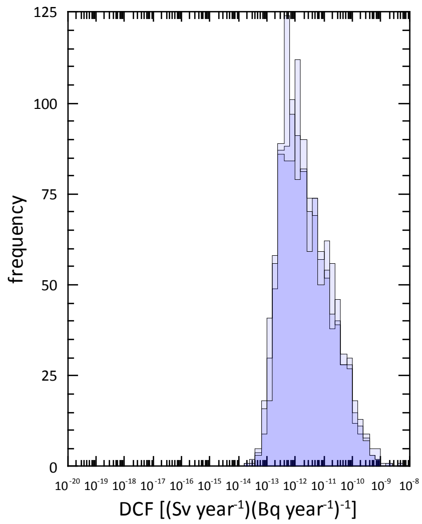
(a) ^{59}Ni – Bedrock well (peat model outlined in red)



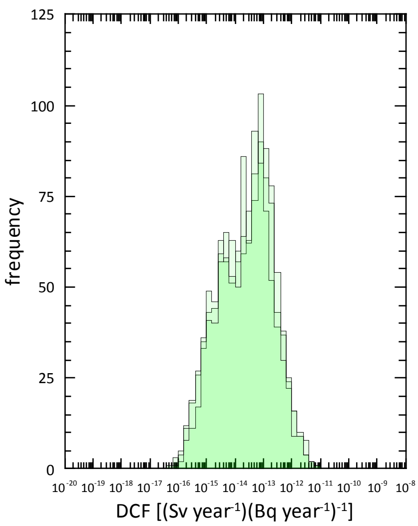
(b) ^{36}Cl – Bedrock well (peat model outlined in red)



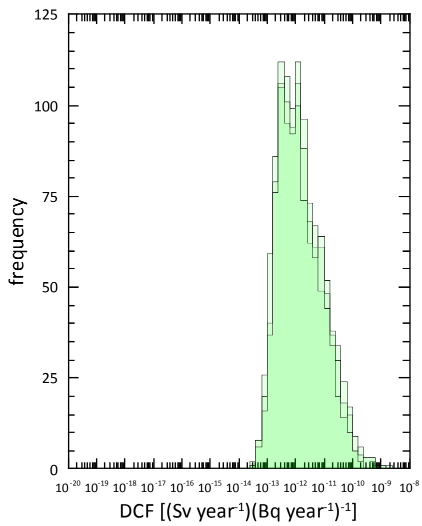
(c) ^{59}Ni – Overburden well



(d) ^{36}Cl – Overburden well



(e) ^{59}Ni – Accumulation / exposure



(f) ^{36}Cl – Accumulation / exposure

Figure 11. Comparison of calculated distributions of DCFs for ^{59}Ni and ^{36}Cl. Plots are shown for the three most significant landscape object types. Each plot shows the calculated distribution for each of the soil types.

most recent compilation from SKB (Tröjbom, *et al.*, 2013) but these values are more suited to the Swedish context. A more complete dataset (in terms of radionuclides) for local conditions should be sought by Posiva for future assessments. It is understood that this is being actively pursued in the current phase of model development and site characterisation by Posiva.

4.5 Implications for dose assessment modelling

Compared to the Ruokola (2000) modelling there is now much more emphasis on the processes that give rise to accumulation. Where objects featuring these FEPs were downplayed in the earlier modelling, the state of knowledge concerning the site description has developed to the extent that it is now possible to make suitably sophisticated models for the accumulation/exposure object (broadly equivalent to the mire model in Ruokola, 2000 model). For this reason many of the calculated RCLs are now more restrictive than in the original calculations.

A major lesson from the analysis of the landscape data in the Posiva (2016) data release is that the geosphere–biosphere interface is an important and relatively less understood part of the Overburden system. In the models here this domain is identified as the lower Overburden. Although it is largely uniform in composition (glacial till) it varies in thickness over the area of interest. The sensitivity analysis shows that it has important implications for the dilution of radionuclides entering from the bedrock. Indeed, were the lower Overburden *not* included in the models here (ie, if the models were closer in concept to the Ruokola, 2000, models) concentrations in the upper Overburden would be much higher and calculated RCLs much more restrictive.

The representation of the lower Overburden here is relatively simplistic as befits the requirements of the RCL calculations. A single compartment is used. This can lead to significant numerical dispersion in the model since there is rapid equilibration of the radionuclide concentration throughout the volume of the compartment. With a compartment several metres thick, this leads to earlier releases to the soil layers. Calculated DCFs may be higher than is realistic. However it should be noted that the long-term equilibrium is reasonably represented by the concentrations calculated in the models described here.

The RCLs models are intended for times beyond 10 kyear AP. Much of the detail in the landscape data description (Posiva, 2016) is directly relevant to the modelling of the evolving landscape in the first 10 kyear AP. Potential radiological impacts in this period are to be addressed in a detailed evolving model for this time period. There may be some feedback that can be used to improve the RCL calculations as a result, particularly with respect to the lower Overburden.

^{14}C remains an important radionuclide for both spent-fuel and LILW repositories. The recent Saetre *et al.* (2013) model with the Grolander (2013) and Tröjbom, *et al.* (2013) datasets offers a suitable alternative to the model employed here. Including ^{14}C as an explicit alternative radionuclide in the evolving models would be practical.

5 Project summary

5.1 Overview

The results of the probabilistic re-evaluation of Release Constraint Limits for the time period beyond a few millennia suggests that a number of changes should be made to both the numerical values and to the way in which they should be used and interpreted in long timescale performance assessments. The principal reason for changing the usage of the RCL values is that the results obtained here reflect a greater degree of site specific data and it should be recognised that where the current values are intended as generic values suitable for the whole of Finland the derivation of the new set of RCLs are contingent on more regional considerations, namely the detailed description of the likely landscape features in the future evolution of coastal southwestern Finland.

The revised understanding and description of the surface ecosystems that has been developed over the fifteen years, since the promulgation of the current RCL values, has allowed more detailed descriptions of the types of landscape object into which future releases are likely to occur. While the broad classification of the objects remains as identified by Ruokola (2002), understanding of the Overburden, hydrology and nuclide specific databases has developed significantly. Evolution of surface systems as a result of isostatic landrise also plays an important role in determining the types of ecosystem and landscape objects into which future potential releases might occur. This is an important region-specific feature of the site.

Results from the revised RCL models show that the key feature of landscape objects that can lead to higher doses is accumulation. For chronic releases from the bedrock there can be significant accumulation in the Overburden. Objects that persist for several thousand years can accumulate higher concentrations of activity, objects that have lower persistence will accumulate lower concentrations and will have correspondingly lower doses. The rapid evolution of the landscape is important.

Thickness of the Overburden is relatively low on current terrestrial areas (above present-day sea level). In lower-lying areas (below current sea level) there is ongoing sedimentation adding to the already thicker Overburden layers. Future releases are likely to be to such areas. The thickness of the Overburden *below the soil layers used for cultivation* is an important feature of the system description that was not taken into account in the original RCL modelling. The deeper the Overburden the lower the concentration overall as well as the longer the transit times for radionuclides releases from the bedrock to the surface layers of the Overburden, ie the soils.

Different types of Overburden material are present in the area around Olkiluoto. The most recent review of radionuclide data (SKB, 2014; Tröjbom *et al.*, 2013) have been used as the nuclide-specific database.

The landscape objects that dominate the RCL evaluation are Bedrock Wells, Overburden Wells and Drained Wetlands (the Accumulation-Exposure object). The first of these assumes deep wells are used to abstract contaminated water from the bedrock. Input to the biosphere is via well water for irrigation and water consumption by humans and livestock. The latter two assume input to the lower Overburden from the bedrock. Well abstraction is from the lower Overburden. To allow for accumulation in the lower OB where the well is located the calculation is evaluated for 10 kyear. This is conservative since agriculture is not likely at the same location over such an extended period. To address this concern the accumulation-exposure scenario assumes that, as a wetland, the object might accumulate activity over an extended period (up to

Table 6. Recommended Geo-Bio constraints (RCLs – Release Constraint Limits) based on the 2016 probabilistic modelling of key landscape features of the future Olkiluoto landscape. Arithmetic mean of the calculated DCFs are used to generate the RCL values.

nuclide	RCL GBq a^{-1}	nuclide	RCL GBq a^{-1}
Cm-245	0.003	Sm-151	10
Am-243	0.003	Cs-135	0.1
Am-241	0.01	I-129	0.003
Pu-239	0.001	Sn-126	0.003
Np-237	0.003	Pd-107	3
U-238	0.01	Tc-99	1
U-235	0.01	Nb-94	0.003
Pa-231	0.001	Zr-93	1
Th-229	0.001	Se-79	0.3
Ra-226	0.001	Ni-59	3
		Cl-36	0.1
		C-14	0.3

10 kyear over which period the distribution of most radionuclides will have reached or be close to steady state conditions) but that cultivation and land use (including an Overburden well) is only possible with the implementation of a managed surface drainage system. Accumulation is determined over the full 10 kyear period with modifications to the radionuclide transport model for the fifty years following conversion. Results from these two conservative variants give consistent results.

The implementation here is inherently probabilistic. Ranges of values for landscape characteristics (dimensions and physical properties) as well as nuclide specific kds and concentration ratios are included. In this way a full expression of the site description (in respect of transport and accumulation characteristics) is included in the derivation of the results. Three statistics have been used to evaluate the dose conversion factors used to scale releases from the geosphere – the arithmetic and geometric means of total dose over all pathways and the corresponding median. The arithmetic mean values are the more conservative of the three statistics and the mean geometric mean and median values are similar. The range is up to 25 times the median (for one radionuclide) but for most the range is a factor of five (13 out of the 22 nuclides considered). As a conservative measure, therefore, the arithmetic mean of dose over all pathways in the evaluation of the landscape objects' dose conversion factors is suggested as the performance indicator by which the Release Constraint Limits are determined. The suggested values are set out in Table 6. As with the original Ruokola (2002) publication the numerical values have been rounded to one significant figure and are quoted as either 1 or 3 depending on the magnitude of the RCL.

Compared to the 2002 results the new RCLs are more restrictive. This is mainly a result of the increased level of detail in the models which focuses on accumulation as the key issue determining future doses. In particular, the accumulation-exposure scenario has features that correspond in part to the bog scenario that was evaluated by Ruokola (2000) but not included in the final determination of the RCLs because of the uncertainties inherent in the interpretation of the future Finnish landscape at that time.

5.2 Recommendations

Current regulations (STUK, 2013, as quoted on page 1 above) state that *the disposal of nuclear waste shall be so designed that, as a consequence of expected evolution, the average long-term quantities of radioactive materials released into the living environment from disposed nuclear waste remain below the constraints specified separately for each nuclide.*

The RCLs therefore have a rather strict interpretation at present. As stated by Ruokola (2002), the main reason for the choice of the geosphere-biosphere flux as the safety indicator was *to exclude from the safety case the great uncertainties related to the evolution of the biosphere in the far future.* It was recognised that the burden on consideration of uncertainties related to evolution of the biosphere in the very long term rests on the rulemaker.

The situation now is somewhat different with respect to the understanding of site characteristics and the expected evolution over the next few millennia. Indeed in Sweden, SKB's recent SR-PSU has carried out detailed dose calculations as far as 100 kyear in to the future with some success (SKB, 2014), although this is still under regulatory review. Nevertheless it is clear that suitable characterisation programmes can significantly reduce the uncertainties relative to what they were in the year 2000 and the time of the determination of the current RCLs.

It is therefore recommended that:

- The RCL values developed here should replace the existing values in STUK's regulations.
- The new RCLs could be used as *Action Levels* so that any breach of the values should be treated as prompt for more detailed investigation by the facility proponent. Acceptability of any safety case might therefore require more detailed justification, including a detailed analysis of doses in the biosphere, by the proponent. The requirement would be that STUK should be satisfied with any additional analyses.
- Consideration might be given the option of removing the RCLs from Guidance. New types of requirements instead (calculating the release and the release leading to dose limit would then be required).

The RCLs derived here are inherently site-specific – they are derived using a considerable quantity of detailed site-specific information. Consideration might therefore be given to retaining the current RCL values for more generic application in Finland, perhaps in early stages of site selection and project planning.

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APPENDIX A – Models for the RCL derivation

Accumulation-Exposure models (wetland → cultivated land)

- RCM2016_SA_Acc_Exp_clay _lognrm_Af.eas
- RCM2016_SA_Acc_Exp_mud _lognrm_Af.eas
- RCM2016_SA_Acc_Exp_peat_lognrm_Af.eas
- RCM2016_SA_Acc_Exp_peat_lognrm_Af_xcor.eas (model with test of interparameter correlations)

Combined with details in the earlier reports (Kłos, 2016abcd) the material in Appendices A, B and C should allow the calculations to be reproduced.

Accumulation in lake beds is required to complete the set of exposure scenarios in the probabilistic RCL modelling. A variant of the small lake scenario is employed. The reason for this is that the large and medium lakes have persistence in the surface environment considerably potentially longer than the 10 kyear limit for which accumulation scenarios in the surface system are intended.

While not exactly a direct modification of the small lake model, the accumulation exposure scenario is a combination of both small scale cultivation and the lake/wetland accumulation cases. In the earlier model development there had not been a self-contained model that performed all the accumulation/exposure (A–E) calculations. First, therefore it is necessary to configure the model with

two time domains. The accumulation time (10^4 years for maximum accumulation in the lake/wetland) and the next fifty years corresponding to the land as drained and converted for cultivation.

In the first 10 kyear the model takes the form of the lake sediment model (with maximum OB thickness assumed). After the transition to agriculture the mode is that of the OB well case both with irrigation from the OB well and without. This confirms that the A–E scenario can be represented by the OB well case with 10 kyear accumulation.

In practical terms the RCL model for accumulation-exposure *must* include an element of change. This can be handled with a simple system – that of the OBW – in which the LOB, Deep and Top compartments have the characteristics of a lake/wetland up until the time of transition and those of the agricultural system thereafter. This simplifies a little but the timing of the transition and the way in which the transfer coefficients are handled are key.

The implementation therefore has two stages, before and after transition. The hydrology of the natural (accumulation) and cultivated (exposure) states are shown above.

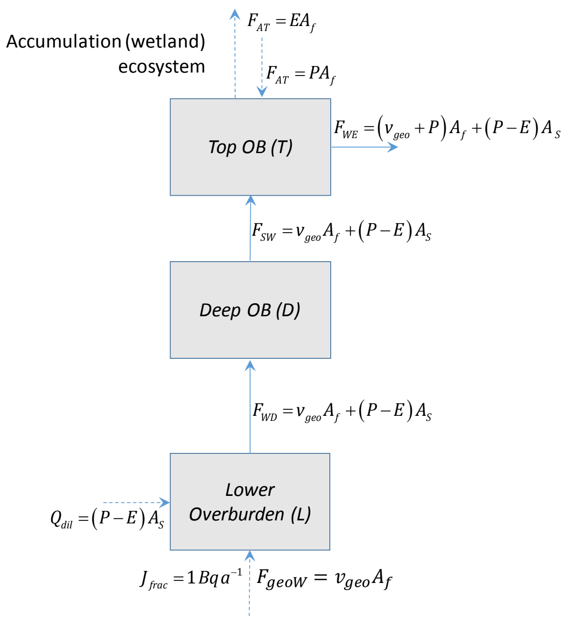
The system corresponds to a small basin into which the geosphere discharges contaminated groundwater with an areal average velocity of 0.006 m year^{-1}. This is not a sensitive parameter but it does drive the water fluxes from the bedrock. From Tables 4-9, 4-17, 4-26, 4-40 in Posiva (2014a), Chapter 4 the range is v_{geo} = uniform(0.002, 0.018) m year^{-1}. This is valid for all RCL PUSA models. If there is an uncontaminated sub-catchment, this has area A_s and it differs from the area of the lake/wetland (ie A_f m²) here that is converted to cultivated land. These values are taken from Appendix B, the area of small catchments around lakes is used, with

- GM = 77188.9297 = 7.7e+04 m²
- GSD= 1.946374668 = 2
- min= 1.2e+04 m²
- max = 3e+05 m².

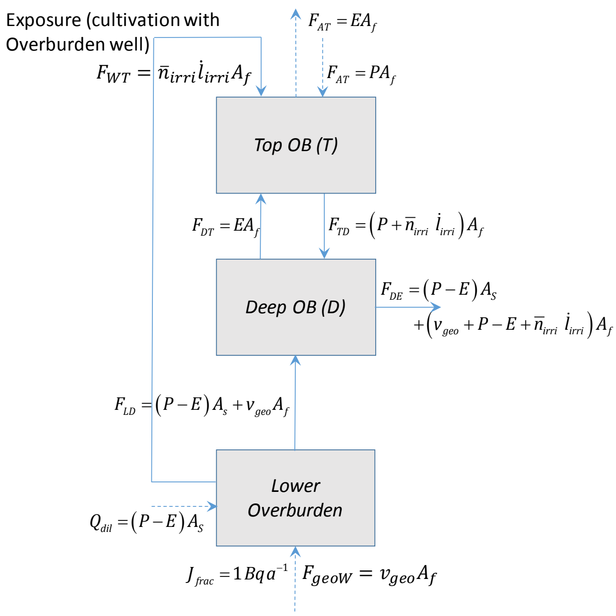
Lake areas are different. These are treated as log uniform between the limits noted in the landscape review report (5e3 to 3e5), the lower OB thickness is similarly from this source but is uniform. However, 10^4 m² is taken to be the lower limit for self-sufficient cultivation (and this is somewhat restrictive).

For the subcatchment, however, the area is taken from the GM17 analysis of lake catchments in the landscape, with the above numbers rounded:

parameter			reference value	pdf	lower	upper	comment
Cultivated area	A_f	m²	1.0E+04	log-uniform	1.0E+04	3.0E+05	area of lake/wetland
parameter			**GM**	**pdf**	**GSD**	**Tr. min**	**Tr. Max**
Sub-catchment	A_s	m²	1.0E+05	log-uniform	2.0E+00	1.0E+04	3.0E+05



Hydrology of natural soils



Hydrology of cultivated soils

Compartment characteristics are tabled below:

		Density	Porosity	VMC	Thickness	Chemistry
		ρ	ε	θ	l	K_d
		kg dw m^{-3}	–	–	m	(Bq kg^{-1} dw) (Bq m^{-3})$^{-1}$
Top Soil	accumulation	rho_T_acc	eps_T_acc	theta_T_acc	l_T_acc	KD_regoUp_ter
	BE	rho_D_acc	eps_D_acc	eps_D_acc	0.3*L_D_acc	KD_regoPG
	pdf	same material as deep soil				KD_regoGL
	exposure	rho_T_exp	eps_D_exp	theta_T_exp	l_T_exp	KD_regoUp_drain
	BE	l_T_acc/l_T_exp * rho_D_acc	0.4	0.3	0.3	KD_regoUp_garden
Deep Soil	accumulation	rho_D_acc	eps_D_acc	theta_D_acc	l_D_acc	KD_regoPeat
	BE	827	0.4	eps_D_acc	0.7	KD_regoPG
	pdf	logu(min=125.0, max=2900.0, trmin=125.0, trmax= 2900.0)	unif(min=0.24, max=0.96, trmin= 0.24, trmax=0.96)	saturated	unif(min=0.5, max=1.5, trmin=0.5, trmax=1.5)	KD_regoGL
	exposure	rho_D_exp	eps_D_exp	theta_D_exp	l_D_exp	KD_regoPeat
	BE	827	0.4	eps_D_acc	0.7	KD_regoPG
	pdf	l_D_acc/l_D_exp * rho_D_acc	fixed values for cultivation			
LOB	acc/exp	rho_L	eps_L	theta_L	l_L	KD_regoLow
	BE	2220	0.2	eps_L	1	
	pdf	unif(min=2000.0, max=2900.0, trmin=2000.0, trmax= 2900.0)	unif(min=0.2, max=0.5, trmin=0.2, trmax=0.5)	saturated	unif(min=0.5, max=6.0, trmin=0.5, trmax=6.0)	

Notes:

- Both deep and top soil are assumed to be compacted so the density is allowed to change on transition to agriculture.
- The top soil compartment of the agricultural system corresponds to the upper 30% the total accumulation soil compartment.

In the Ecolego model, these transfers are parameterised as follows.

For each of the transfer coefficients there will be an accumulation and an exposure variant so that the implemented transfer rates are:
lam_i_j = if (time < 10000, lm_i_j_acc, lm_i_j_exp))

Accumulation phase – 3 active transfers

*lm_LOB_D_acc =(v_geo*Af + (P – E)*As) / l_LOB / R_LOB / Af*

lm_LOB_T_acc = 0

*lm_D_T_acc = (v_geo*Af + (P – E)*As) / l_LOB / R_LOB / l_D_acc / R_D*

lm_T_D_acc = 0

lm_D_E_acc = 0

*lm_T_E_acc = ((P-E)*As+(v_geo+P-E) * Af) / l_D_acc / R_D / Af*

Exposure phase 5 active transfers

*lm_LOB_D_exp = (v_geo*Af + (P-E)*As) / l_LOB / R_LOB / Af*

*lm_LOB_T_exp = (n_irri_gveg+n_irri_root+n_irri_cereal+n_irri_past) / 4.0 * ldot_irri / l_LOB / R_LOB*

lm_D_T_exp = E / l_D_exp / R_D

*lm_T_D_exp = (P + (n_irri_gveg+n_irri_root+n_irri_cereal+n_irri_past) / 4.0 * ldot_irri) / l_T_exp / R_T*

*lm_D_E_exp = ((P - E) * As + (v_geo + P -E + (n_irri_gveg+n_irri_root+n_irri_cereal+n_irri_past) / 4.0 * ldot_irri)) * Af) / l_D_exp / R_D / Af*

lm_T_E_exp = 0

Calculation of doses

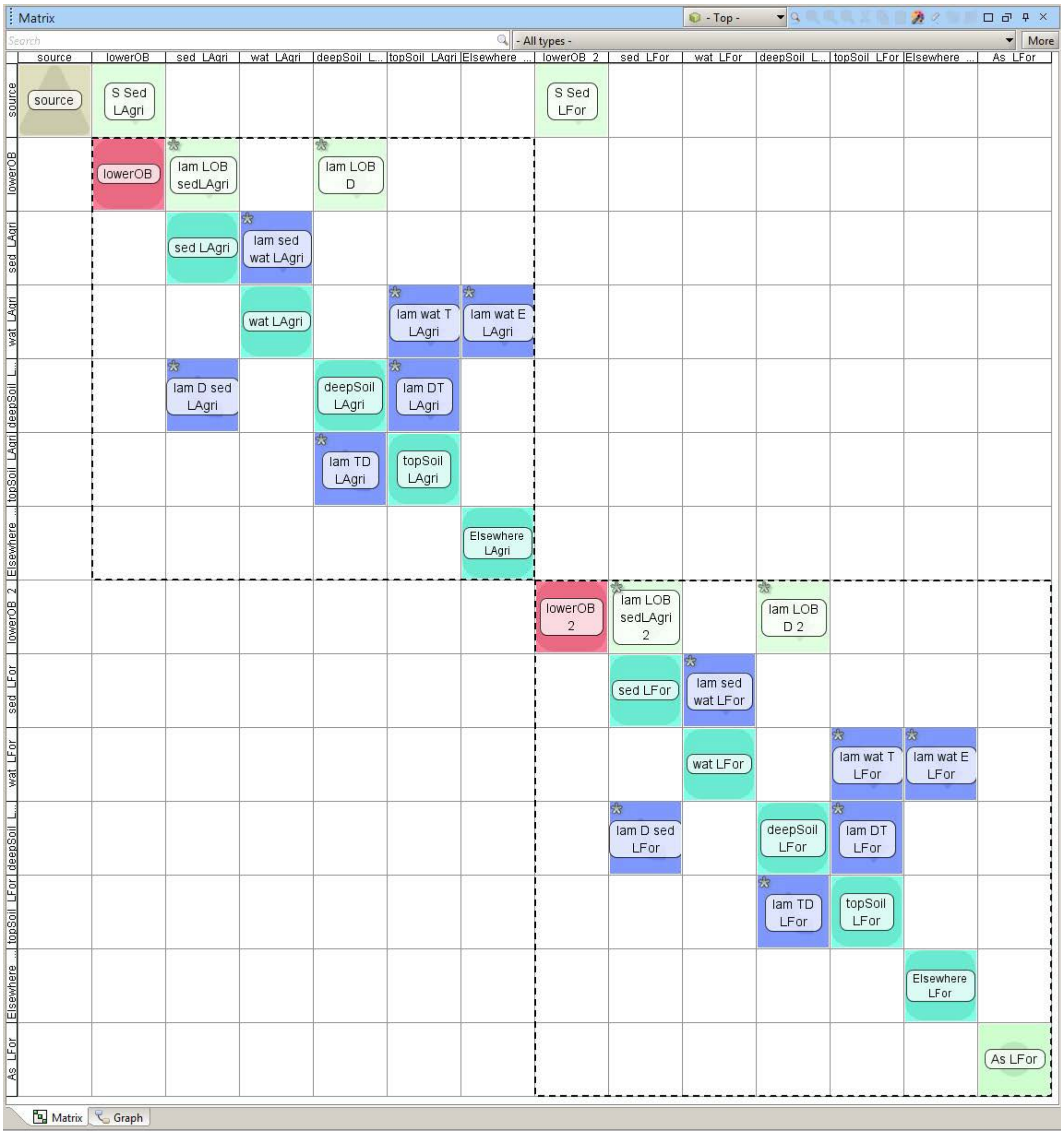
Peak doses are likely to arise close to the time of transition. For this reason provision is included to calculate the total dose at each of the times from the first year after transition to the 50th. This allows the mean adult lifetime dose to be calculated for this period. Particularly for the weaker sorbing radionuclides there can be noticeable leaching from the upper soils.

Limitations in Ecolego mean that estimation of the mean is more complex than might be expected in the probabilistic modelling. The dose at the 25th year after transition is therefore used as a surrogate for the mean. For immobile radionuclides this value is similar to the mean. For more mobile radionuclides the difference has been found to be small.

The doses in the A–E model are therefore quoted at 10025 CE, assuming an accumulation time of 10 kyear.

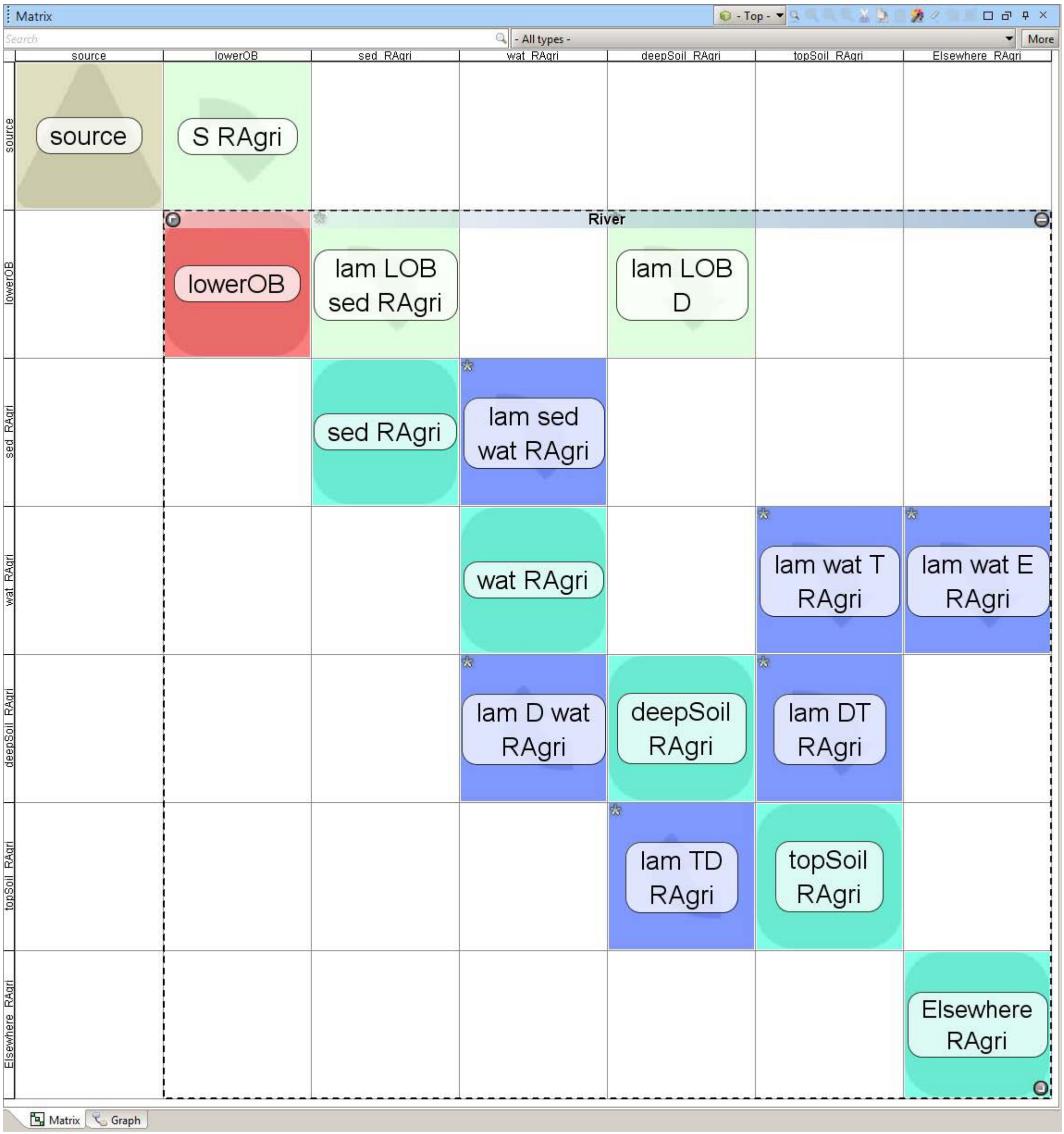
Lakes (lake with agricultural soils / lake with natural soils) – see Kłos (2016ac)

- RCM2016_SA_LargeLakes_Clay.eas
- RCM2016_SA_LargeLakes_Mud.eas
- RCM2016_SA_LargeLakes_Peat.eas
- RCM2016_SA_MediumLakes_Clay.eas
- RCM2016_SA_MediumLakes_Mud.eas
- RCM2016_SA_MediumLakes_Peat.eas
- RCM2016_SA_SmallLakes_Clay.eas
- RCM2016_SA_SmallLakes_Mud.eas
- RCM2016_SA_SmallLakes_Peat.eas



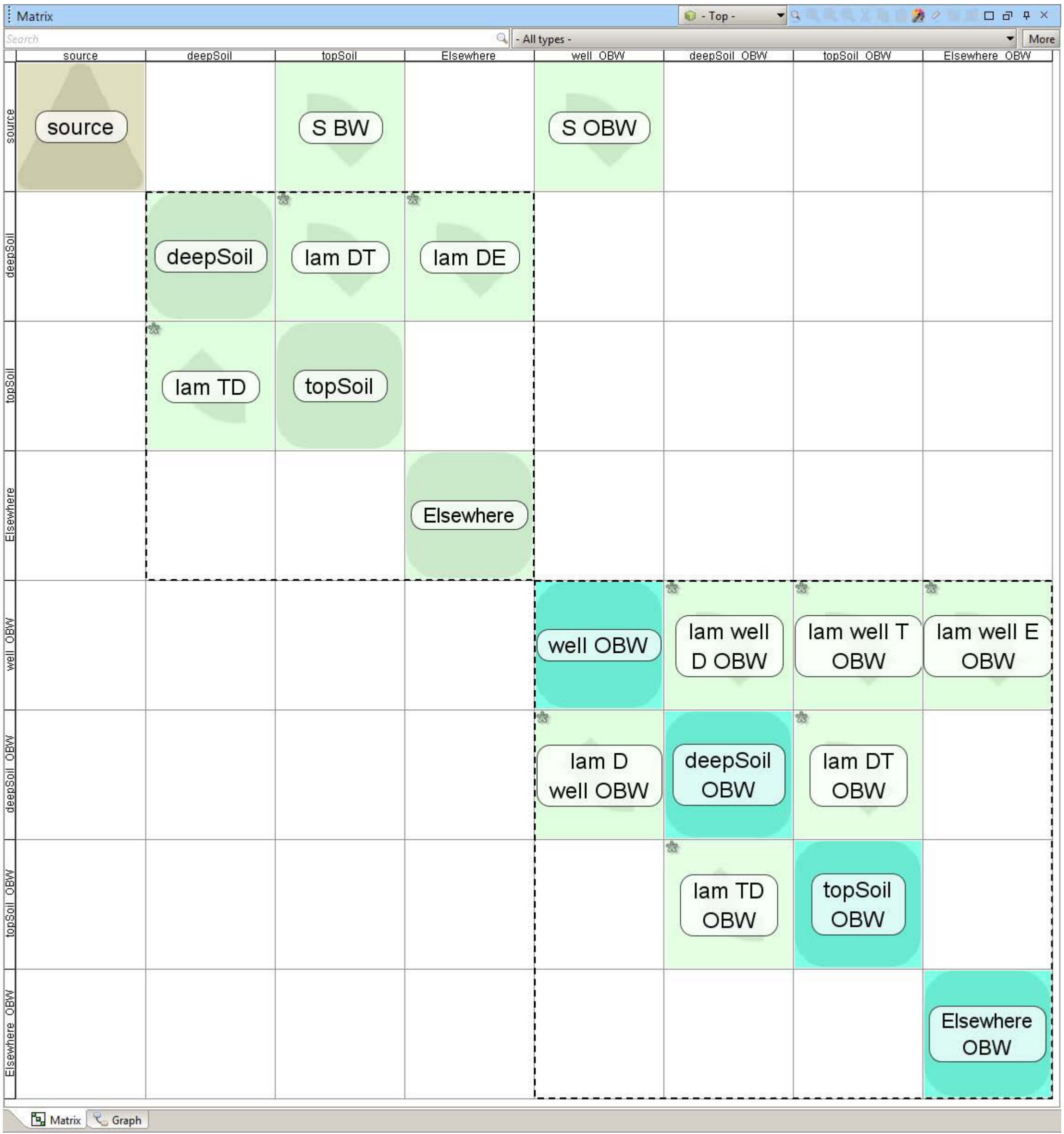
Rivers – see Kłos (2016ac)

RCM2016_SA_LocalRivers_Clay.eas
RCM2016_SA_LocalRivers_Mud.eas
RCM2016_SA_LocalRivers_Peat.eas
RCM2016_SA_RegionalRivers_Clay.eas
RCM2016_SA_RegionalRivers_Mud.eas
RCM2016_SA_RegionalRivers_Peat.eas
RCM2016_SA_TributaryRivers_Clay.eas
RCM2016_SA_TributaryRivers_Mud.eas
RCM2016_SA_TributaryRivers_Peat.eas



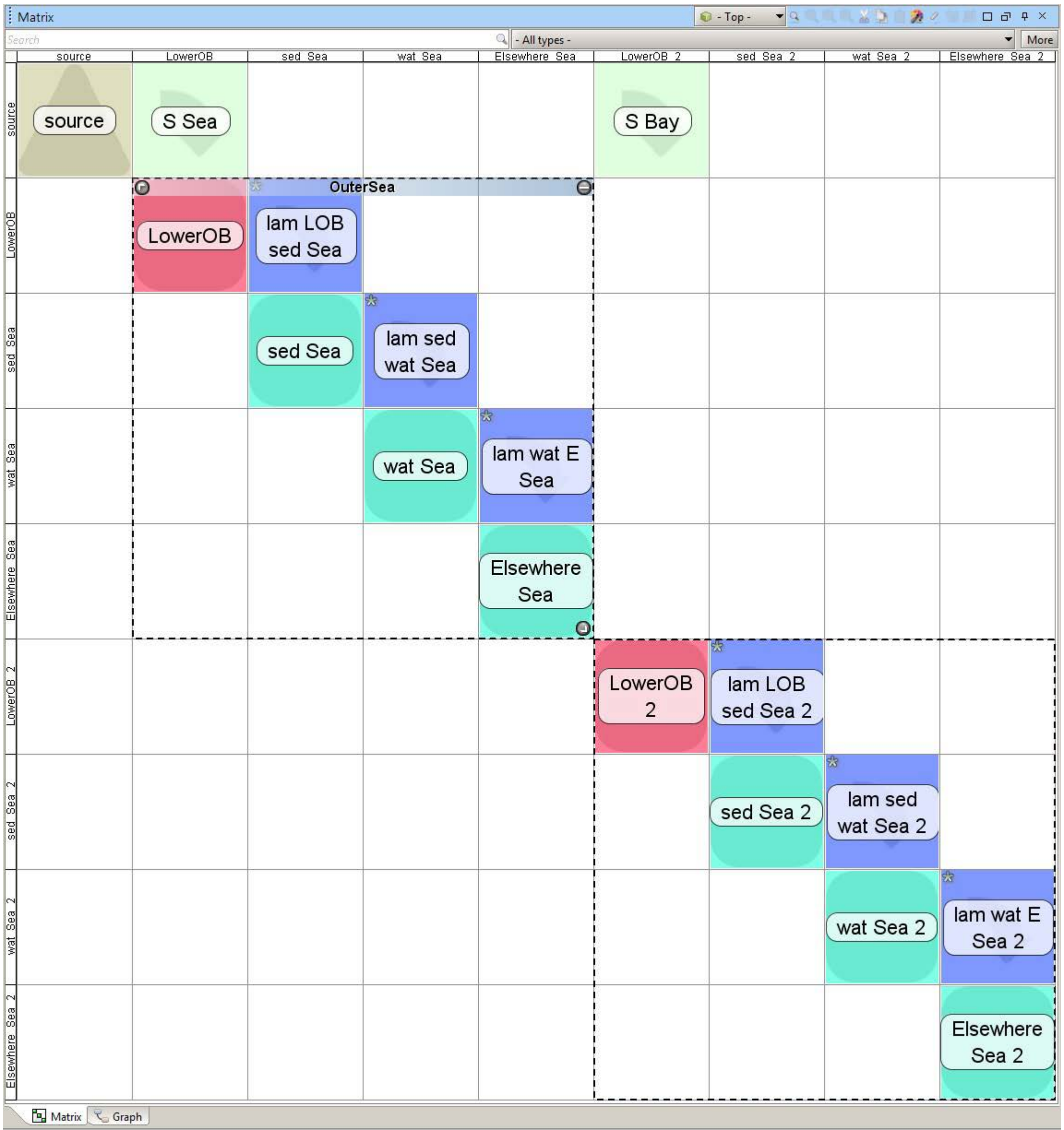
Wells – bedrock and Overburden – see Kłos (2016ac)

- RCM2016_SA_wellsClay.eas
- RCM2016_SA_wellsMud.eas
- RCM2016_SA_wellsPeat.eas



Coast – see Kłos (2016ac)

- RCM2016_SA_coast.eas



APPENDIX B – Parameters from the landscape model review

Region specific parameters

Ecolego model parameter		Units	BE	pdf	Source
Precipitation	P	$m^3\ m^{-2}\ year^{-1}$	0.55	Uniform (0.41,0.709)	POSIVA (2014a) 2012-28
Evapotranspiration	E	$m^3\ m^{-2}\ year^{-1}$	0.39	–	POSIVA (2014a) 2012-28 – assumed constant for temperate climate
Geosphere release velocity	v_geo	$m^3\ m^{-2}\ year^{-1}$	0.004	Uniform (0.002,0.018)	POSIVA (2014a) 2012-28
Thickness lower OB	l_LOB	m	1.0	Uniform (0.5, 6.0)	Kłos (2016d)
Thickness mid OB	l_D	m	0.7	uniform (0.5, 1.5)	Assumption
Thickness upper OB	l_T	m	0.3	uniform (0.2,0.5)	Assumption
Density lower OB	rho_LOB	$kg\ m^{-3}$	2220	Uniform (2000, 2900)	POSIVA (2014a) 2012-28 (converted to grain density from bulk density)
Density mid OB	rho_D	$kg\ m^{-3}$	2000	Loguniform 125, 2900	Full range from POSIVA (2014a) 2012-28
Density upper OB	rho_T	$kg\ m^{-3}$	2000	Loguniform 125, 2900	Full range from POSIVA (2014a) 2012-28
Porosity lower OB	epsilon_LOB	unitless	0.4	Uniform (0.2, 0.5)	POSIVA (2014a) 2012-28
Porosity mid OB	epsilon _D	unitless	0.4	Uniform 0.24, 0.96	Full range from POSIVA (2014a) 2012-28
Porosity upper OB	epsilon _T	unitless	0.4	Constant for cultivated soils	Assumed maintained for cultivation
Volumetric moisture content lower OB	theta_LOB	unitless	= epsilon_well_OBW		Assumed saturated, so equal to porosity
Volumetric moisture content mid OB	theta_D	unitless	0.4	Equal to porosity – saturated	Assumption
Volumetric moisture content upper OB	theta_T	unitless	0.3	Constant for cultivated soils	Assumption

- Areas of land determined in respect of terrestrial landscape on Olkiluoto island.
- The model uses grain density, related to bulk density by $\rho_{bulk} = (1 - \varepsilon)\ \rho_{grain}$.
- Deep soil is assumed saturated so that $\theta_{deepsoil} = \varepsilon_{deepsoil}$. Top soil is assumed to be maintained in good condition for agriculture so $\varepsilon_{topsoil} = 0.4$, $\theta_{topsoil} = 0.3$.

Bedrock well, Overburden Well

Ecolego model parameter	Units	BE (Klos, 2016a)	pdf	Source
Area of cultivated land *Af*	m²	100000	Lognormal μ = 8e4 σ = 1.73 t_{rmin} = 1e+04 t_{rmax} = 1e+06	Catchment size analysis with GM17.
Diluting flow in bed-rock fracture Qdil	m³ year⁻¹	90000	Loguniform 1e+04 , 1e+06	Rough range from Klos (2014a)
Dilution in lower Overburden well *Qdil*	m³ year⁻¹	–	–	Defined as (P - E)**Af_OBW*

Rivers

The lower overburden compartment receives input from the bedrock with the groundwater input v_{geo} m year⁻¹. Transfers from this compartment to the aquatic bed sediment and the adjacent soils are given by

$$\lambda_{\substack{lowerOB\\sedAgri}} = \frac{v_{geo} A_s}{R_{lowerOB} l_{lowerOB} \left(A_s + A_f\right)}$$

$$R_{lowerOB} = \theta_{lowerOB} + \left(1 - \varepsilon_{lowerOB}\right) \rho_{lowerOB} K_{d,lowerOB}$$

$$\lambda_{\substack{lowerOB\\D}} = \frac{v_{geo} A_f}{R_{lowerOB} l_{lowerOB} \left(A_s + A_f\right)}$$

$$R_{lowerOB} = \theta_{lowerOB} + \left(1 - \varepsilon_{lowerOB}\right) \rho_{lowerOB} K_{d,lowerOB}$$

Tributary Rivers

This model corresponds to the potential release to "uplands" catchments with no upstream through flow. Flow in the river is therefore determined by the accumulation in the autogenic catchment area. Catchment areas are the same as for small lakes (above). The area for the river is more difficult to determine.

The sample of 128 autogenic catchments in the 12020 CE landscape gives the following statistics:

	length	area
μ	3.50E+02	1.64E+05
σ	3.07E+02	3.09E+05
min	2.79E+01	5.26E+04
max	1.84E+03	2.76E+06
GM	2.5E+02	1.2E+05
GSD	2.3	1.9

- Area of river: lognormal(gm=250.0,gsd=2.3, trmin=20.0,trmax=2000.0)
- Area of cultivation: lognormal(gm=77000.0,gsd= 2.0,trmin=12000.0,trmax=300000.0).

Geometry of the streams is unknown. It is assumed that for these small streams that the width is 0.5 m.

Regional and Local Rivers

Drainage in the Eurajoki and Lapinjoki rivers are, from Posiva-2011-02 (Site Description, page 91), respectively:

Two regionally large rivers, the Lapinjoki and the Eurajoki, discharge to the sea north and east of Olkiluoto Island, increasing the concentrations of nutrients and solids, especially at the river mouths. The average outflow of the River Eurajoki is 6–12 m/s, being about 2.5 times of that of the River Lapinjoki (Environmental information and spatial data service – OIVA portal, May 4, 2009). The cooling water from the NPPs changes the flow conditions and increases the seawater temperature. At present, the NPPs consume a total of 5.2 million m³/d of cooling water, which is six times the mean flow of the River Eurajoki, and causes a rise of 13.6°C in the cooling water temperature (Kirkkala & Turkki 2005 Chapters 4 and 5; Turkki 2006 pp. 6). Elsewhere, the normal differences between archipelago and open sea areas were observed: the sea temperatures of the inner archipelago were approximately 4–5°C higher than those of the open sea.

From this description:

- Flow in Eurajoki = $F_{Eurajoki}$ = 5.2E6 / 6 m³ day 1 = 3.2e+08 m³ year⁻¹
- Flow in Lapinjoki = $F_{Lapinjoki}$ = $F_{Eurajoki}$ / 2.5= 5.2E6 / 6 / 2.5 m³ day⁻¹ = 1.3e+08 m³ year⁻¹.

River	flow rate m^3 day^{-1}	m^3 $year^{-1}$	m^3 s^{-1}	P m $year^{-1}$	E m $year^{-1}$	upstream catchment m^2	Reference
Eurajoki	8.7E+05	3.2E+08	1.0E+01	0.55	0.39	2.0E+09	Posiva (2012b)
Lapinjoki	3.5E+05	1.3E+08	4.0E+00			7.9E+08	

These values are used as they are with no variation. The variation in the river flow is assumed to come from the size of the local subcatchments that border the main drainage channel in the model area. This defines the overall flow in the *Regional River* model.

Maps of the region (Google Maps) indicate that the southern channel is fed by local catchments whereas the flow to the northern channel is fed by the two regional rivers. As shown above, the flow in the more northern Eurajoki is higher.

The consequences for the regional river model is that the "upstream catchment" area varies from a low of the combined Eurajoki and Lapinjoki catchments to that value plus the total area of the *northern* basin only.

Catchment areas m^2		extracted	2sf	selected
Northern upstream Catchment:	Max	45192898	4.5E+07	5.0E+07
	Min	9481465	9.5E+06	1.0E+07
Southern upstream Catchment:	Max	28251713	2.8E+07	5.0E+07
	Min	15678932	1.6E+07	1.0E+07

Uniform distributions are assumed.

The differences between the three river models are as follows: In practice the parameter *A_up_local* is selected for the *Regional River* model but deselected for the tributary river case. Similarly the contribution of the regional rivers (Eurajoki and Lapinjoki) is included by setting the parameter *A_up_region* to either 0 (tributary river, *Local River* model, ie, southern channel drainage) or 3×10^9 m^2 (northern channel with regional rivers included). Thickness of OB is the same for both sets of calculations.

Lakes

Allowing for the lower Overburden compartment that underlies the model area, transfers are coded as:

$$\lambda_{sedAgri}^{lowerOB} = \frac{v_{geo} A_s}{R_{lowerOB} l_{lowerOB} \left(A_s + A_f\right)}$$

$$R_{lowerOB} = \theta_{lowerOB} + \left(1 - \varepsilon_{lowerOB}\right) \rho_{lowerOB} K_{d,lowerOB}$$

$$\lambda_{D}^{lowerOB} = \frac{v_{geo} A_f}{R_{lowerOB} l_{lowerOB} \left(A_s + A_f\right)}$$

$$R_{lowerOB} = \theta_{lowerOB} + \left(1 - \varepsilon_{lowerOB}\right) \rho_{lowerOB} K_{d,lowerOB}$$

relative to the Kłos (2016a) models.

In the original modelling the 1 Bq $year^{-1}$ release was arbitrarily partitioned as 0.5 each to the lake bed and the deep soil. This has been amended since the areas of lake and farmed land are allowed to vary.

The following parameters are used for the three sizes of lake:

Lake type	parameter			min	max	pdf
small	Area	*As*	m^2	5.0E+03	5.0E+05	loguniform
	OB thickness	l_{LOB}	m^2	1	6	uniform
	persistence	–	kyear	3		–
medium	Area	*As*	m^2	1.0E+05	1.0E+06	loguniform
	OB thickness	l_{LOB}	m^2	2	5	uniform
	persistence	–	kyear	8		
large	Area	*As*	m^2	1.00E+06	5.00E+06	loguniform
	OB thickness	l_{LOB}	m^2	2	10	uniform
	persistence	–	kyear	10		

Adjacent soils of both natural and agricultural type are assumed. To do this the model parameters are interpreted as follows. Note that the treatment of the upstream catchments is the same as for the river models.

Small lakes

*Lam_wat_E_RAgri = (Q_upstream+Q_dil_RAgri+(v_geo_RAgri+P-E)*As_RAgri)/ (l_wat_RAgri*R_wat_RAgri*As_RAgri)*

*Q_dil_RAgri = (P-E+(n_irri_gveg+n_irri_root+n_irri_cereal+n_irri_past)/4.0*ldot_irri)*Af_RAgri*

Q_upstream = (P-E)(A_up_local+A_up_region)*

A_up_local = 0.0

A_up_region = 0.0

*Lam_wat_E_LFor = ((Q_upstream+Q_dil_LFor+(v_geo_LFor+P))*As_LFor+(v_geo_LFor+P-E)*Af_LFor)/ (R_wat_LFor*l_wat_LFor*As_LFor)*

*Q_dil_LFor = (P-E)*Af_RAgri*

Q_upstream = (P-E)(A_up_local+A_up_region)*

A_up_local = 0.0

A_up_region = 0.0

Medium lakes

*Lam_wat_E_RAgri = (Q_upstream+Q_dil_RAgri+(v_geo_RAgri+P-E)*As_RAgri)/ (l_wat_RAgri*R_wat_RAgri*As_RAgri)*

*Q_dil_RAgri = (P-E+(n_irri_gveg+n_irri_root+n_irri_cereal+n_irri_past)/4.0*ldot_irri)*Af_RAgri*

Q_upstream = (P-E)(A_up_local+A_up_region)*

A_up_local = unif(min=1.0E7,max=5.0E7,trmin=1.0E7,trmax=5.0E7)

A_up_region = 0.0

*Lam_wat_E_LFor = ((Q_upstream+Q_dil_LFor+(v_geo_LFor+P))*As_LFor+(v_geo_LFor+P-E)*Af_LFor)/ (R_wat_LFor*l_wat_LFor*As_LFor)*

*Q_dil_LFor = (P-E)*Af_RAgri*

Q_upstream = (P-E)(A_up_local+A_up_region)*

A_up_local = unif(min=1.0E7,max=5.0E7,trmin=1.0E7,trmax=5.0E7)

A_up_region = 0.0

Large lakes

*Lam_wat_E_RAgri = (Q_upstream+Q_dil_RAgri+(v_geo_RAgri+P-E)*As_RAgri)/ (l_wat_RAgri*R_wat_RAgri*As_RAgri)*

*Q_dil_RAgri = (P-E+(n_irri_gveg+n_irri_root+n_irri_cereal+n_irri_past)/4.0*ldot_irri)*Af_RAgri*

Q_upstream = (P-E)(A_up_local+A_up_region)*

A_up_local = unif(min=1.0E7,max=5.0E7,trmin=1.0E7,trmax=5.0E7)

A_up_region = 3.0e+09

*Lam_wat_E_LFor = ((Q_upstream+Q_dil_LFor+(v_geo_LFor+P))*As_LFor+(v_geo_LFor+P-E)*Af_LFor)/ (R_wat_LFor*l_wat_LFor*As_LFor)*

*Q_dil_LFor = (P-E)*Af_RAgri*

Q_upstream = (P-E)(A_up_local+A_up_region)*

A_up_local = unif(min=1.0E7,max=5.0E7,trmin=1.0E7,trmax=5.0E7)

A_up_region = 3.0e+09

Sea and Bay objects

The original 2016 RCL model is simplistic with respect to marine ecosystems. Open sea was assumed with consumption of marine foodstuffs.

This model also adds a lower OB compartment with water flux through determined by the parameter. The depth is varied as is the area but these are largely irrelevant as the dilution is determined by the water retention parameter. In fact, as noted on page 74 of Posiva 2012-28, the sea around the island in the present day can be classified as "coastal waters". Water retention in the Posiva 2012-30 dataset is difficult to find. The value used is taken from Karlsson & Bergström (2000) which distinguishes outer and inner seas. For bays the runoff from the inland catchments is also included.

For the bay areas – similar to large, wide and narrow lakes – the turnover time is given by

$$\lambda_{exchange} = \frac{1}{V_{wat}} \frac{dV_{wat}}{dt} = \frac{1}{\tau_{ret}},$$

and for bays,

$$\frac{dV_{bay}}{dt} = \left(P - E\right) A_{catch},$$

so that

$$\tau_{ret} = \frac{l_{wat} A_s}{\left(P - E\right) A_{catch}}.$$

Ecolego parameter		Units		Outer sea	Inner sea	Bay	Reference
Thickness lower OB	l_LOB	m	BE	0.5	0.5	0.5	Landscape modelling review Low minimum => absence
			pdf	triangular	triangular	triangular	
			min	0.5	0.01	0.5	
			max	3.5	3.5	3.5	
			comment	Consistent with Karlsson & Bergström (2000)			
Depth water column	l_wat	m	BE	9	5	1	Landscape modelling review
			pdf	triangular	triangular	triangular	
			min	8	2	0.5	
			max	10	8	2	2010 maps
			comment		first approximation		
Area, aquatic object	As	m²	BE	4.3E+05	1.0E+06	5.0E+04	Karlsson & Bergström (2000) & Landscape model review (inner sea as outer sea in Karlsson & Bergström (2000))
			pdf	log triangular	log triangular	log triangular	
			min	1.3E+05	8.0E+05	5.0E+03	
			max	8.3E+05	1.2E+06	5.0E+05	
			comment	POSIVA 2000-20	POSIVA 2000-20	Landscape review	
Water retention time	tau_ret	day	BE	7.3	0.73	–	POSIVA 2000-20
			pdf	triangular	triangular	–	
			min	5	0.5	–	
			max	10	1	–	
			comment	–	–	–	
Terrestrial catchment area	Catchment	m²	BE	–	–	8.3E+05	Landscape modelling review – derived from morphology of bays.
			pdf	–	–	log triangular	
			min	–	–	2.0E+05	
			max	–	–	3.3E+06	
			comment	–	–		
K_d Lower OB	kd_LOB	m³ kg⁻¹	–	kd_regoLow	kd_regoLow	kd_regoLow	Assumed, SR-PSU
Water retention time	tau_ret	year	BE	2.0e-02	2.0e-03	–	Karlsson & Bergström (2000)
			pdf	triangular	triangular	–	
			min	1.4e-02	1.4e-03	–	
			max	2.7e-02	2.7e-03	–	
			comment	–	–	–	
Thickness, sediment layer	l_sed	m	BE		0.5	0.5	Landscape modelling review Low minimum => absence
			pdf		triangular	triangular	
			min		0.01	0.5	
			max		3.5	3.5	
			comment	Consistent with Karlsson & Bergström (2000)			Same as for till layer

APPENDIX C – Nuclide specific data

Solid-liquid distribution coefficients taken from Tröjbom *et al.* (2013). The selected pdf is loguniform with the best estimate as shown. Units are (Bq kg^{-1} dw)(Bq m^{-3})$^{-1}$. Data from Tröjbom *et al.* (2013) converted from kgC to kg fw or dw as required.

The numerical values used here are collected to allow the results to be re-evaluated if required.

Parameter	Radionuclide	BE	min	max	Radionuclide	BE	min	max
KD_rego_aqu	Cm-245	88	4.8E-01	6.8E+02	U-238	4.5	2.9E-03	8.1E+01
KD_regoGL		100	4.8E-01	6.8E+02		0.43	2.9E-03	8.1E+01
KD_regoLow		11	4.8E-01	6.8E+02		0.022	2.9E-03	8.1E+01
KD_regoPeat		10	4.8E-01	6.8E+02		13	2.9E-03	8.1E+01
KD_regoPG		3.5	4.8E-01	6.8E+02		3.8	2.9E-03	8.1E+01
KD_regoUp_drain		5.5	4.8E-01	6.8E+02		5.9	2.9E-03	8.1E+01
KD_regoUp_garden		21	4.8E-01	6.8E+02		0.38	2.9E-03	8.1E+01
KD_regoUp_ter		12	4.8E-01	6.8E+02		10	2.9E-03	8.1E+01
KD_rego_aqu	Am-243	88	4.8E-01	6.8E+02	U-235	4.5	2.9E-03	8.1E+01
KD_regoGL		100	4.8E-01	6.8E+02		0.43	2.9E-03	8.1E+01
KD_regoLow		11	4.8E-01	6.8E+02		0.022	2.9E-03	8.1E+01
KD_regoPeat		10	4.8E-01	6.8E+02		13	2.9E-03	8.1E+01
KD_regoPG		3.5	4.8E-01	6.8E+02		3.8	2.9E-03	8.1E+01
KD_regoUp_drain		5.5	4.8E-01	6.8E+02		5.9	2.9E-03	8.1E+01
KD_regoUp_garden		21	4.8E-01	6.8E+02		0.38	2.9E-03	8.1E+01
KD_regoUp_ter		12	4.8E-01	6.8E+02		10	2.9E-03	8.1E+01
KD_rego_aqu	Am-241	88	4.8E-01	6.8E+02	Pa-231	88	4.8E-01	6.8E+02
KD_regoGL		100	4.8E-01	6.8E+02		100	4.8E-01	6.8E+02
KD_regoLow		11	4.8E-01	6.8E+02		11	4.8E-01	6.8E+02
KD_regoPeat		10	4.8E-01	6.8E+02		10	4.8E-01	6.8E+02
KD_regoPG		3.5	4.8E-01	6.8E+02		3.5	4.8E-01	6.8E+02
KD_regoUp_drain		5.5	4.8E-01	6.8E+02		5.5	4.8E-01	6.8E+02
KD_regoUp_garden		21	4.8E-01	6.8E+02		21	4.8E-01	6.8E+02
KD_regoUp_ter		12	4.8E-01	6.8E+02		12	4.8E-01	6.8E+02
KD_rego_aqu	Pu-239	4.5	1.4E-01	6.8E+02	Th-229	210	3.7E-01	9.0E+02
KD_regoGL		100	1.4E-01	6.8E+02		93	3.7E-01	9.0E+02
KD_regoLow		11	1.4E-01	6.8E+02		24	3.7E-01	9.0E+02
KD_regoPeat		10	1.4E-01	6.8E+02		3.2	3.7E-01	9.0E+02
KD_regoPG		3.5	1.4E-01	6.8E+02		13	3.7E-01	9.0E+02
KD_regoUp_drain		5.9	1.4E-01	6.8E+02		4	3.7E-01	9.0E+02
KD_regoUp_garden		0.38	1.4E-01	6.8E+02		25	3.7E-01	9.0E+02
KD_regoUp_ter		10	1.4E-01	6.8E+02		2.8	3.7E-01	9.0E+02
KD_rego_aqu	Np-237	88	4.2E-01	5.7E+02	Ra-226	3.2	2.3E-01	6.2E+01
KD_regoGL		93	4.2E-01	5.7E+02		10	2.3E-01	6.2E+01
KD_regoLow		24	4.2E-01	5.7E+02		1.4	2.3E-01	6.2E+01
KD_regoPeat		3.2	4.2E-01	5.7E+02		2.1	2.3E-01	6.2E+01
KD_regoPG		13	4.2E-01	5.7E+02		2.6	2.3E-01	6.2E+01
KD_regoUp_drain		5.5	4.2E-01	5.7E+02		2.1	2.3E-01	6.2E+01
KD_regoUp_garden		21	4.2E-01	5.7E+02		6	2.3E-01	6.2E+01
KD_regoUp_ter		12	4.2E-01	5.7E+02		2.1	2.3E-01	6.2E+01

Parameter	Radionuclide	BE	min	max	Radionuclide	BE	min	max
KD_rego_aqu	C-14	0.001	4.0E-04	7.0E-01	Tc-99	0.18	9.2E-03	3.3E+02
KD_regoGL		0.001	4.0E-04	7.0E-01		54	9.2E-03	3.3E+02
KD_regoLow		0.001	4.0E-04	7.0E-01		3.6	9.2E-03	3.3E+02
KD_regoPeat		0.07	4.0E-04	7.0E-01		2.6	9.2E-03	3.3E+02
KD_regoPG		0.07	4.0E-04	7.0E-01		4.1	9.2E-03	3.3E+02
KD_regoUp_drain		0.07	4.0E-04	7.0E-01		0.067	9.2E-03	3.3E+02
KD_regoUp_garden		0.001	4.0E-04	7.0E-01		0.11	9.2E-03	3.3E+02
KD_regoUp_ter		0.07	4.0E-04	7.0E-01		0.41	9.2E-03	3.3E+02
KD_rego_aqu	Cl-36	0.009	8.8E-05	2.5E-01	Pd-107	14	1.2E-01	1.0E+02
KD_regoGL		0.0051	8.8E-05	2.5E-01		17	1.2E-01	1.0E+02
KD_regoLow		0.0005	8.8E-05	2.5E-01		0.79	1.2E-01	1.0E+02
KD_regoPeat		0.027	8.8E-05	2.5E-01		4.3	1.2E-01	1.0E+02
KD_regoPG		0.0084	8.8E-05	2.5E-01		1.1	1.2E-01	1.0E+02
KD_regoUp_drain		0.021	8.8E-05	2.5E-01		0.64	1.2E-01	1.0E+02
KD_regoUp_garden		0.0058	8.8E-05	2.5E-01		4.6	1.2E-01	1.0E+02
KD_regoUp_ter		0.021	8.8E-05	2.5E-01		1.9	1.2E-01	1.0E+02
KD_rego_aqu	Ni-59	14	6.0E-02	1.0E+02	Sn-126	9.6	4.8E-01	1.1E+03
KD_regoGL		17	6.0E-02	1.0E+02		13	4.8E-01	1.1E+03
KD_regoLow		0.79	6.0E-02	1.0E+02		11	4.8E-01	1.1E+03
KD_regoPeat		2.6	6.0E-02	1.0E+02		10	4.8E-01	1.1E+03
KD_regoPG		1.1	6.0E-02	1.0E+02		27	4.8E-01	1.1E+03
KD_regoUp_drain		0.83	6.0E-02	1.0E+02		5.5	4.8E-01	1.1E+03
KD_regoUp_garden		2.6	6.0E-02	1.0E+02		8.3	4.8E-01	1.1E+03
KD_regoUp_ter		1.9	6.0E-02	1.0E+02		5.2	4.8E-01	1.1E+03
KD_rego_aqu	Se-79	4.4	2.3E-02	4.6E+01	I-129	0.35	2.3E-03	4.4E+00
KD_regoGL		0.92	2.3E-02	4.6E+01		0.23	2.3E-03	4.4E+00
KD_regoLow		0.14	2.3E-02	4.6E+01		0.014	2.3E-03	4.4E+00
KD_regoPeat		0.44	2.3E-02	4.6E+01		0.73	2.3E-03	4.4E+00
KD_regoPG		1.5	2.3E-02	4.6E+01		0.48	2.3E-03	4.4E+00
KD_regoUp_drain		1.3	2.3E-02	4.6E+01		0.14	2.3E-03	4.4E+00
KD_regoUp_garden		0.98	2.3E-02	4.6E+01		0.2	2.3E-03	4.4E+00
KD_regoUp_ter		1	2.3E-02	4.6E+01		0.2	2.3E-03	4.4E+00
KD_rego_aqu	Nb-94	150	8.0E-01	9.2E+02	Cs-135	46	4.1E-03	2.5E+03
KD_regoGL		150	8.0E-01	9.2E+02		330	4.1E-03	2.5E+03
KD_regoLow		31	8.0E-01	9.2E+02		12	4.1E-03	2.5E+03
KD_regoPeat		12	8.0E-01	9.2E+02		0.47	4.1E-03	2.5E+03
KD_regoPG		31	8.0E-01	9.2E+02		43	4.1E-03	2.5E+03
KD_regoUp_drain		3.9	8.0E-01	9.2E+02		11	4.1E-03	2.5E+03
KD_regoUp_garden		22	8.0E-01	9.2E+02		250	4.1E-03	2.5E+03
KD_regoUp_ter		7.3	8.0E-01	9.2E+02		0.46	4.1E-03	2.5E+03
KD_rego_aqu	Zr-93	89	2.5E-03	8.0E+02	Sm-151	88	3.3E-02	6.8E+02
KD_regoGL		54	2.5E-03	8.0E+02		100	3.3E-02	6.8E+02
KD_regoLow		3.6	2.5E-03	8.0E+02		11	3.3E-02	6.8E+02
KD_regoPeat		2.6	2.5E-03	8.0E+02		10	3.3E-02	6.8E+02
KD_regoPG		4.1	2.5E-03	8.0E+02		3.5	3.3E-02	6.8E+02
KD_regoUp_drain		0.89	2.5E-03	8.0E+02		5.5	3.3E-02	6.8E+02
KD_regoUp_garden		2.2	2.5E-03	8.0E+02		21	3.3E-02	6.8E+02
KD_regoUp_ter		2.3	2.5E-03	8.0E+02		12	3.3E-02	6.8E+02

Soil-plant concentration factors and concentration ratios: truncated lognormal

Name	Unit	Nuclide	BE	GM	GSD	Lower	Upper	Reference
K_cereal	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹	Cl-36	3.285	3.29E+00	3	1.22E-01	2.03E+01	POSIVA 2012-28
K_crust_fw	m³ kg⁻¹		0.019	5.40E-02	5	2.70E-03	7.60E-01	POSIVA 2012-28
K_crust_sea	unitless		1.5	6.00E-05	5	4.20E-06	8.50E-04	POSIVA 2012-28
K_f	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		35.19	3.52E+01	4	3.62E+00	3.47E+02	POSIVA 2012-28
K_fish_fw	m³ kg⁻¹		0.0001408	3.10E-02	3.2	3.10E-03	2.82E-01	POSIVA 2012-28
K_fish_sea	m³ kg⁻¹		0.0001408	1.69E-04	3	2.82E-05	1.07E-03	POSIVA 2012-28
K_gveg	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		35.19	3.52E+01	4	3.62E+00	3.47E+02	POSIVA 2012-28
K_m	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		179.4	1.79E+02	7	3.27E+00	4.42E+03	POSIVA 2012-28
K_p	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		49	4.90E+01	7	1.00E+00	1.20E+03	POSIVA 2012-28
K_root	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		17.34	1.73E+01	1.8	1.79E+00	1.68E+02	POSIVA 2012-28
K_cereal	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹	Ni-59	0.0072	7.20E-03	3.1	6.75E-04	2.34E-01	POSIVA 2012-28
K_crust_fw	m³ kg⁻¹		0.28	2.50E-01	5	1.80E-02	3.50E+00	POSIVA 2012-28
K_crust_sea	unitless		5.7	5.70E+00	5	4.00E-01	8.10E+01	POSIVA 2012-28
K_f	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.0612	7.14E-02	7	2.91E-03	1.79E+00	POSIVA 2012-28
K_fish_fw	m³ kg⁻¹		0.026752	9.15E-03	5	6.48E-04	1.30E-01	POSIVA 2012-28
K_fish_sea	m³ kg⁻¹		0.026752	2.68E-02	3	4.36E-03	1.69E-01	POSIVA 2012-28
K_gveg	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.0612	7.14E-02	7	2.91E-03	1.79E+00	POSIVA 2012-28
K_m	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.1518	1.52E-01	3	6.90E-03	1.56E+00	POSIVA 2012-28
K_p	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.015	1.70E-02	7	7.10E-04	4.30E-01	POSIVA 2012-28
K_root	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.0612	7.14E-02	7	2.91E-03	1.79E+00	POSIVA 2012-28
K_cereal	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹	Se-79	0.0252	2.52E-02	4	2.61E-03	2.48E-01	POSIVA 2012-28
K_crust_fw	m³ kg⁻¹		3	3.00E+00	5	2.10E-01	4.20E+01	POSIVA 2012-28
K_crust_sea	unitless		0.0036	1.50E+00	5	1.10E-01	2.20E+01	POSIVA 2012-28
K_f	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.02856	2.86E-02	7	1.17E-03	7.14E-01	POSIVA 2012-28
K_fish_fw	m³ kg⁻¹		5.4912	1.22E+00	3	1.97E-01	7.46E+00	POSIVA 2012-28
K_fish_sea	m³ kg⁻¹		5.4912	4.93E+00	3	8.03E-01	2.96E+01	POSIVA 2012-28
K_gveg	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.02856	2.86E-02	7	1.17E-03	7.14E-01	POSIVA 2012-28
K_m	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.02576	2.58E-02	7	1.06E-03	6.44E-01	POSIVA 2012-28
K_p	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.0062	6.20E-03	7	2.50E-04	1.50E-01	POSIVA 2012-28
K_root	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.02856	2.86E-02	7	1.17E-03	7.14E-01	POSIVA 2012-28
K_cereal	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹	Zr-93	0.03375	3.38E-02	3.7	3.29E-03	2.21E+00	POSIVA 2012-28
K_crust_fw	m³ kg⁻¹		0.1	1.50E-01	5	1.00E-02	2.10E+00	POSIVA 2012-28
K_crust_sea	unitless		11	1.10E+01	5	7.60E-01	1.50E+02	POSIVA 2012-28
K_f	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.00561	5.61E-03	7	2.19E-04	1.33E-01	POSIVA 2012-28
K_fish_fw	m³ kg⁻¹		0.22528	3.24E-02	3	5.21E-03	1.97E-01	POSIVA 2012-28
K_fish_sea	m³ kg⁻¹		0.22528	1.97E-01	3.5	1.38E-02	3.80E+00	POSIVA 2012-28
K_gveg	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.00561	5.61E-03	7	2.19E-04	1.33E-01	POSIVA 2012-28
K_m	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.01104	1.29E-02	7	5.06E-04	3.13E-01	POSIVA 2012-28
K_p	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.003	3.40E-03	7	1.40E-04	8.30E-02	POSIVA 2012-28
K_root	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.01224	1.43E-02	7	5.61E-04	3.47E-01	POSIVA 2012-28
K_cereal	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹	Nb-94	0.00441	4.41E-03	6.3	2.16E-04	8.55E-01	POSIVA 2012-28
K_crust_fw	m³ kg⁻¹		0.7	5.20E-01	5	3.70E-02	7.40E+00	POSIVA 2012-28
K_crust_sea	unitless		0.59	1.00E-01	5	7.10E-03	1.40E+00	POSIVA 2012-28
K_f	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.02295	2.30E-02	7	9.18E-04	5.61E-01	POSIVA 2012-28
K_fish_fw	m³ kg⁻¹		0.02112	1.14E-02	3	1.83E-03	6.90E-02	POSIVA 2012-28
K_fish_sea	m³ kg⁻¹		0.02112	2.11E-02	5	1.55E-03	2.96E-01	POSIVA 2012-28
K_gveg	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.02295	2.30E-02	7	9.18E-04	5.61E-01	POSIVA 2012-28
K_m	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.00368	3.73E-03	7	1.52E-04	2.25E-01	POSIVA 2012-28
K_p	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.001	9.90E-04	7	4.00E-05	5.40E-02	POSIVA 2012-28
K_root	(Bq kg⁻¹)(Bq kg⁻¹)⁻¹		0.004947	4.95E-03	7	2.04E-04	1.22E-01	POSIVA 2012-28

Soil-plant concentration factors and concentration ratios: truncated lognormal

Name	Unit	Nuclide	BE	GM	GSD	Lower	Upper	Reference
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Tc-99	0.0288	2.88E-02	5.1	4.05E-04	2.03E+00	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.013	1.30E-02	5	9.20E-04	1.80E-01	POSIVA 2012-28
K_crust_sea	unitless		0.45	1.60E+01	2.3	5.00E-02	1.80E+02	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.03264	3.26E-02	7	4.59E-04	2.30E+00	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.018304	3.66E-02	5	2.53E-03	5.07E-01	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.018304	1.83E-02	3.3	2.53E-03	4.79E-01	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.03264	3.26E-02	7	4.59E-04	2.30E+00	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.02944	2.94E-02	7	4.14E-04	2.07E+00	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0071	7.10E-03	7	1.00E-04	5.10E-01	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.2856	2.86E-01	4	1.63E-02	2.81E+00	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Pd-107	0.0072	7.20E-03	3.1	6.75E-04	2.34E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.28	2.50E-01	5	1.80E-02	3.50E+00	POSIVA 2012-28
K_crust_sea	unitless		5.7	5.70E+00	5	4.00E-01	8.10E+01	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0612	7.14E-02	7	2.91E-03	1.79E+00	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.026752	9.15E-03	5	6.48E-04	1.30E-01	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.026752	2.68E-02	3	4.36E-03	1.69E-01	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0612	7.14E-02	7	2.91E-03	1.79E+00	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.1518	1.52E-01	3	6.90E-03	1.56E+00	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.015	1.70E-02	7	7.10E-04	4.30E-01	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0612	7.14E-02	7	2.91E-03	1.79E+00	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Sn-126	0.01665	1.67E-02	3	2.43E-03	1.04E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.1	1.50E-01	5	1.00E-02	2.10E+00	POSIVA 2012-28
K_crust_sea	unitless		0.1	4.50E-01	5	3.20E-02	6.30E+00	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.001632	1.63E-03	6	8.67E-05	2.86E-01	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.54912	3.24E-02	3	5.21E-03	1.97E-01	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.54912	5.49E-01	5	3.94E-02	7.88E+00	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.001632	1.63E-03	6	8.67E-05	2.86E-01	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0046	4.60E-03	3.9	3.27E-04	2.81E-01	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.015	1.40E-02	7	5.80E-04	3.50E-01	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0002499	2.50E-04	9.9	5.61E-06	2.24E-02	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	I-129	0.01215	1.22E-02	3.6	6.75E-04	2.97E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.22	1.50E-01	5	1.10E-02	2.20E+00	POSIVA 2012-28
K_crust_sea	unitless		8.2	3.60E-03	5	2.50E-04	5.10E-02	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00867	8.67E-03	4	9.18E-04	1.38E-01	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.030976	6.48E-02	3	1.07E-02	3.94E-01	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.030976	2.68E-02	3	4.51E-03	1.69E-01	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00867	8.67E-03	4	9.18E-04	1.38E-01	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0299	2.99E-02	3	5.06E-03	1.38E+00	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.019	1.90E-02	7	7.80E-04	1.50E+00	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.01122	1.12E-02	3	1.12E-03	1.07E-01	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Cs-135	0.01125	1.13E-02	7.6	3.96E-04	9.45E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.31	4.80E-01	5	3.40E-02	6.80E+00	POSIVA 2012-28
K_crust_sea	unitless		0.00006	5.90E-01	5	4.20E-02	8.30E+00	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0816	8.16E-02	6	4.08E-04	1.53E+00	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.2816	2.82E+00	4.9	7.60E-02	4.36E+01	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.2816	3.10E-01	3	5.07E-02	1.83E+00	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0816	8.16E-02	6	4.08E-04	1.53E+00	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		15.18	1.52E+01	4.7	1.06E-01	5.52E+02	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.044	3.80E-02	7.2	1.10E-03	5.10E+00	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0714	7.14E-02	4	4.95E-03	7.65E-01	POSIVA 2012-28

Soil-plant concentration factors and concentration ratios: truncated lognormal

Name	Unit	Nuclide	BE	GM	GSD	Lower	Upper	Reference
K_cereal	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$	Cm-245	0.002385	2.39E-03	6.5	9.00E-05	3.02E-01	POSIVA 2012-28
K_crust_fw	m^3 kg^{-1}		1.5	3.00E+00	5	2.10E-01	4.20E+01	POSIVA 2012-28
K_crust_sea	unitless		1.5	8.20E+00	5	5.80E-01	1.20E+02	POSIVA 2012-28
K_f	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.001887	1.89E-03	4.5	1.58E-04	2.24E-02	POSIVA 2012-28
K_fish_fw	m^3 kg^{-1}		0.0036608	6.90E-04	3	1.13E-04	5.07E-03	POSIVA 2012-28
K_fish_sea	m^3 kg^{-1}		0.0036608	3.66E-03	5	2.68E-04	1.39E-01	POSIVA 2012-28
K_gveg	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.001887	1.89E-03	4.5	1.58E-04	2.24E-02	POSIVA 2012-28
K_m	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00092	1.47E-03	7	5.06E-05	6.90E-02	POSIVA 2012-28
K_p	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00025	3.90E-04	7	1.40E-05	1.60E-02	POSIVA 2012-28
K_root	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0001836	1.84E-04	4	1.38E-05	2.60E-03	POSIVA 2012-28
K_cereal	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$	Am-243	0.002385	2.39E-03	6.5	9.00E-05	3.02E-01	POSIVA 2012-28
K_crust_fw	m^3 kg^{-1}		1.5	3.00E+00	5	2.10E-01	4.20E+01	POSIVA 2012-28
K_crust_sea	unitless		8.2	8.20E+00	5	5.80E-01	1.20E+02	POSIVA 2012-28
K_f	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0003672	3.67E-04	4	3.77E-05	3.57E-03	POSIVA 2012-28
K_fish_fw	m^3 kg^{-1}		0.0036608	6.90E-04	3	1.13E-04	5.07E-03	POSIVA 2012-28
K_fish_sea	m^3 kg^{-1}		0.0036608	3.66E-03	5	2.68E-04	1.39E-01	POSIVA 2012-28
K_gveg	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0003672	3.67E-04	4	3.77E-05	3.57E-03	POSIVA 2012-28
K_m	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00092	1.47E-03	7	5.06E-05	6.90E-02	POSIVA 2012-28
K_p	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00025	3.90E-04	7	1.40E-05	1.60E-02	POSIVA 2012-28
K_root	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0002601	2.60E-04	6	1.38E-05	4.23E-02	POSIVA 2012-28
K_cereal	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$	Am-241	0.002385	2.39E-03	6.5	9.00E-05	3.02E-01	POSIVA 2012-28
K_crust_fw	m^3 kg^{-1}		1.5	3.00E+00	5	2.10E-01	4.20E+01	POSIVA 2012-28
K_crust_sea	unitless		8.2	8.20E+00	5	5.80E-01	1.20E+02	POSIVA 2012-28
K_f	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0003672	3.67E-04	4	3.77E-05	3.57E-03	POSIVA 2012-28
K_fish_fw	m^3 kg^{-1}		0.0036608	6.90E-04	3	1.13E-04	5.07E-03	POSIVA 2012-28
K_fish_sea	m^3 kg^{-1}		0.0036608	3.66E-03	5	2.68E-04	1.39E-01	POSIVA 2012-28
K_gveg	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0003672	3.67E-04	4	3.77E-05	3.57E-03	POSIVA 2012-28
K_m	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00092	1.47E-03	7	5.06E-05	6.90E-02	POSIVA 2012-28
K_p	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00025	3.90E-04	7	1.40E-05	1.60E-02	POSIVA 2012-28
K_root	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0002601	2.60E-04	6	1.38E-05	4.23E-02	POSIVA 2012-28
K_cereal	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$	Pu-239	0.001755	1.76E-03	10.4	1.26E-05	8.55E-01	POSIVA 2012-28
K_crust_fw	m^3 kg^{-1}		1	1.00E+00	5	7.30E-02	1.40E+01	POSIVA 2012-28
K_crust_sea	unitless		8.2	1.20E-01	2.1	2.00E-02	7.30E-01	POSIVA 2012-28
K_f	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0001122	1.12E-04	4	1.17E-05	1.12E-03	POSIVA 2012-28
K_fish_fw	m^3 kg^{-1}		0.025344	2.53E+01	5	1.83E+00	3.52E+02	POSIVA 2012-28
K_fish_sea	m^3 kg^{-1}		0.025344	2.53E-02	3.8	2.39E-03	4.65E-01	POSIVA 2012-28
K_gveg	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0001122	1.12E-04	4	1.17E-05	1.12E-03	POSIVA 2012-28
K_m	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00414	4.14E-03	9.8	5.52E-05	6.90E+00	POSIVA 2012-28
K_p	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00013	1.40E-04	5.6	2.40E-06	3.40E-02	POSIVA 2012-28
K_root	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.0001377	1.38E-04	5.5	4.69E-06	6.12E-03	POSIVA 2012-28
K_cereal	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$	Np-237	0.002385	2.39E-03	6.5	9.00E-05	3.02E-01	POSIVA 2012-28
K_crust_fw	m^3 kg^{-1}		1.5	3.00E+00	5	2.10E-01	4.20E+01	POSIVA 2012-28
K_crust_sea	unitless		0.12	8.20E+00	5	5.80E-01	1.20E+02	POSIVA 2012-28
K_f	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.03672	3.67E-02	4	3.77E-03	3.57E-01	POSIVA 2012-28
K_fish_fw	m^3 kg^{-1}		0.0036608	1.31E-03	5	9.29E-05	1.83E-02	POSIVA 2012-28
K_fish_sea	m^3 kg^{-1}		0.0036608	3.66E-03	5	2.68E-04	1.39E-01	POSIVA 2012-28
K_gveg	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.03672	3.67E-02	4	3.77E-03	3.57E-01	POSIVA 2012-28
K_m	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00092	1.47E-03	7	5.06E-05	6.90E-02	POSIVA 2012-28
K_p	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00025	3.90E-04	5.6	1.40E-05	1.60E-02	POSIVA 2012-28
K_root	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00714	7.14E-03	4	7.14E-04	7.14E-02	POSIVA 2012-28
K_cereal	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$	U-238	0.001755	1.76E-03	10.4	1.26E-05	8.55E-01	POSIVA 2012-28
K_crust_fw	m^3 kg^{-1}		0.019	9.90E-02	5.6	7.00E-03	1.40E+00	POSIVA 2012-28
K_crust_sea	unitless		0.12	1.00E-02	5	7.10E-04	1.40E-01	POSIVA 2012-28
K_f	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.02703	2.70E-02	7.3	1.07E-04	1.17E+01	POSIVA 2012-28
K_fish_fw	m^3 kg^{-1}		0.00022528	1.55E-04	5	8.31E-06	4.08E-03	POSIVA 2012-28
K_fish_sea	m^3 kg^{-1}		0.00022528	2.25E-04	5	1.55E-05	3.10E-03	POSIVA 2012-28
K_gveg	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.02703	2.70E-02	7.3	1.07E-04	1.17E+01	POSIVA 2012-28
K_m	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00414	4.14E-03	9.8	5.52E-05	6.90E+00	POSIVA 2012-28
K_p	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00013	1.40E-04	7	2.40E-06	3.40E-02	POSIVA 2012-28
K_root	(Bq kg^{-1})(Bq kg^{-1})$^{-1}$		0.00612	6.12E-03	6.4	2.24E-04	1.33E-01	POSIVA 2012-28

Soil-plant concentration factors and concentration ratios: truncated lognormal

Name	Unit	Nuclide	BE	GM	GSD	Lower	Upper	Reference
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	U-235	0.001755	1.76E-03	10.4	1.26E-05	8.55E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.019	9.90E-02	5.6	7.00E-03	1.40E+00	POSIVA 2012-28
K_crust_sea	unitless		0.12	1.00E-02	5	7.10E-04	1.40E-01	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.02703	2.70E-02	7.3	1.07E-04	1.17E+01	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.00022528	1.55E-04	5	8.31E-06	4.08E-03	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.00022528	3.66E-03	5	2.68E-04	1.39E-01	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.02703	2.70E-02	7.3	1.07E-04	1.17E+01	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00414	4.14E-03	9.8	5.52E-05	6.90E+00	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00013	1.40E-04	7	2.40E-06	3.40E-02	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00612	6.12E-03	6.4	2.24E-04	1.33E-01	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Pa-231	0.002385	2.39E-03	6.5	9.00E-05	3.02E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		1.5	3.00E+00	5	2.10E-01	4.20E+01	POSIVA 2012-28
K_crust_sea	unitless		0.01	8.20E+00	5	5.80E-01	1.20E+02	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00765	7.65E-03	4	8.16E-04	7.65E-02	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.0036608	6.90E-04	3	1.13E-04	5.07E-03	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.0036608	3.66E-03	5	2.68E-04	1.39E-01	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00765	7.65E-03	4	8.16E-04	7.65E-02	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00092	1.47E-03	7	5.06E-05	6.90E-02	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00025	3.90E-04	7	1.40E-05	1.60E-02	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0004845	4.85E-04	4	4.95E-05	4.95E-03	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Th-229	0.00369	3.69E-03	6.4	1.76E-04	7.20E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.27	3.90E-01	5	2.70E-02	5.40E+00	POSIVA 2012-28
K_crust_sea	unitless		8.2	2.30E+01	5	1.60E+00	3.20E+02	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.001632	1.63E-03	6	8.67E-05	2.86E-01	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.97152	9.43E-02	2.3	1.55E-02	6.76E-01	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.97152	4.65E-01	3	7.74E-02	2.82E+00	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.001632	1.63E-03	6	8.67E-05	2.86E-01	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0046	4.60E-03	3.9	3.27E-04	2.81E-01	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0014	1.40E-03	7	5.60E-05	3.40E-02	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0002499	2.50E-04	9.9	5.61E-06	2.24E-02	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Ra-226	0.0171	1.71E-02	12	8.10E-05	1.04E+00	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		1.1	1.10E+00	3	1.50E-01	6.90E+00	POSIVA 2012-28
K_crust_sea	unitless		23	1.20E-01	3	2.00E-02	7.40E-01	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.1224	1.22E-01	6.7	2.45E-03	1.79E+02	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.02112	5.77E-03	3	9.43E-04	3.66E-02	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.02112	1.25E-02	3.4	1.55E-03	9.29E-02	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.1224	1.22E-01	6.7	2.45E-03	1.79E+02	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.03174	3.17E-02	3.2	2.67E-03	6.90E-01	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0069	6.90E-03	7	2.80E-04	1.70E-01	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.01377	1.38E-02	6.8	2.96E-04	4.85E+00	POSIVA 2012-28
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	Sm-151	0.0018	1.80E-03	6.4	8.10E-05	1.98E-01	POSIVA 2012-28
K_crust_fw	$m^3\ kg^{-1}$		0.47	9.50E-01	5	6.70E-02	1.30E+01	POSIVA 2012-28
K_crust_sea	unitless		2	2.00E+00	5	1.40E-01	2.80E+01	POSIVA 2012-28
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00765	7.65E-03	4	8.16E-04	7.65E-02	POSIVA 2012-28
K_fish_fw	$m^3\ kg^{-1}$		0.019712	3.66E-03	5	2.53E-04	5.21E-02	POSIVA 2012-28
K_fish_sea	$m^3\ kg^{-1}$		0.019712	1.97E-02	5	1.37E-03	2.68E-01	POSIVA 2012-28
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00765	7.65E-03	4	8.16E-04	7.65E-02	POSIVA 2012-28
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.001288	1.56E-03	7	6.44E-05	4.51E-02	POSIVA 2012-28
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.00035	4.10E-04	7	1.70E-05	1.10E-02	POSIVA 2012-28
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0.0004845	4.85E-04	4	4.95E-05	4.95E-03	POSIVA 2012-28

Soil-plant concentration factors and concentration ratios: Parameters for ^{14}C.

Name	Unit	Nuclide	Value	PDF	Lower	Max	Min	Mode	Upper	Reference
K_cereal	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$	C-14	0	–						
K_crust_fw	$m^3\ kg^{-1}$		9	log-triangular	0.9	10	0.9	9	10	POSIVA 2000-20
K_crust_sea	unitless		9	log-triangular	0.9	10	0.9	9	0.9	POSIVA 2000-20
K_f	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0	–						
K_fish_fw	$m^3\ kg^{-1}$		50	log-triangular	1	60	1	50	60	POSIVA 2000-20
K_fish_sea	$m^3\ kg^{-1}$		2	Triangular	2	3	2	2	3	POSIVA 2000-20
K_gveg	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0	–						
K_m	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0	–						
K_p	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0	–						
K_root	$(Bq\ kg^{-1})(Bq\ kg^{-1})^{-1}$		0	–						

APPENDIX D – Landscape object probabilistic DCF results by radionuclide

The following two tables show the calculated arithmetic mean and median values from the DCF calculations for each radionuclide in each object for each combination of the media. Results are colour-coded from green (lowest dose for the radionuclide) to red (highest). The scaling is such that red and red-orange are in the range 0.7–1.0 of the maximum. Pale orange implies the range 0.1 to 0.7. Yellow and green are 2 to more than three orders of magnitude lower than the maximum. Results for geometric mean are not shown as they are similar to those for the median.

In this way the most important objects for the calculations can be readily identified as the well objects (both bedrock and Overburden sources) and the accumulation/exposure (small lake/wetland converted to agriculture).

Doses from marine objects and from lakes and rivers are all calculated as being less than a tenth of the maximum DCF for each radionuclide. The only exception is for ^{14}C as modelled here where doses from the tributary river model are between 20% (median) and 60% (mean) of the highest DCF.

Mean		Am-243	C-14	Cl-36	Cm-245	Cs-135	I-129	Nb-94	Ni-59	Np-237	Pa-231	Pd-107	Pu-239	Ra-226	Se-79	Sm-151	Sn-126	Tc-99	Th-229	U-238	Zr-93	U-235	Am-241
Accumulation/ Exposure	Peat	1.6E-11	4.0E-13	6.5E-12	1.5E-11	4.4E-12	2.8E-11	6.9E-12	9.7E-14	2.2E-11	6.0E-11	5.2E-14	5.5E-11	3.7E-11	9.7E-13	5.0E-16	1.4E-11	7.3E-13	4.9E-11	2.5E-11	5.9E-13	2.5E-11	7.4E-13
	Mud/gyttja	2.1E-11	4.1E-13	7.7E-12	1.4E-11	3.1E-12	2.7E-11	8.7E-12	1.1E-13	1.5E-11	4.8E-11	4.4E-14	4.4E-11	3.6E-11	1.0E-12	4.7E-16	1.4E-11	6.9E-13	5.4E-11	2.3E-11	6.4E-13	2.9E-11	7.6E-13
	Clay/mineral	1.5E-11	4.1E-13	6.8E-12	1.7E-11	3.4E-12	2.8E-11	6.6E-12	9.0E-14	2.5E-11	6.0E-11	4.4E-14	4.5E-11	3.5E-11	9.9E-13	4.4E-16	1.3E-11	6.6E-13	6.5E-11	2.3E-11	4.1E-13	2.6E-11	7.1E-13
Bedrock wells	Peat	1.8E-11	1.9E-13	4.5E-13	1.9E-11	3.6E-13	9.1E-12	8.5E-14	4.6E-14	9.7E-12	6.3E-11	2.6E-14	2.2E-11	3.2E-11	2.2E-13	8.7E-15	2.0E-13	2.1E-14	5.4E-11	9.2E-12	3.6E-14	8.8E-12	1.8E-11
	Mud/gyttja	1.3E-10	1.9E-13	2.6E-12	1.2E-10	7.4E-12	1.6E-11	1.3E-10	1.3E-13	1.0E-10	3.3E-10	8.4E-14	1.5E-10	2.0E-10	1.2E-12	9.2E-15	1.6E-10	9.9E-13	3.4E-10	2.2E-11	1.0E-12	2.4E-11	2.7E-11
	Clay/mineral	1.4E-10	1.9E-13	3.5E-12	1.4E-10	7.9E-12	1.4E-11	1.2E-10	1.4E-13	1.2E-10	3.3E-10	9.3E-14	1.8E-10	2.4E-10	1.1E-12	9.1E-15	1.6E-10	1.4E-12	3.6E-10	2.1E-11	9.3E-13	2.2E-11	2.8E-11
Overburden Wells	Peat	2.4E-11	4.1E-13	1.3E-11	2.6E-11	4.8E-12	3.1E-11	1.9E-11	1.1E-13	2.6E-11	7.0E-11	6.3E-14	5.8E-11	5.1E-11	1.5E-12	4.6E-16	3.0E-11	7.5E-13	7.9E-11	3.0E-11	6.7E-13	2.7E-11	8.4E-13
	Mud/gyttja	2.1E-11	4.1E-13	1.2E-11	2.3E-11	4.4E-12	3.5E-11	1.7E-11	9.6E-14	2.9E-11	6.4E-11	5.5E-14	6.8E-11	5.1E-11	1.2E-12	4.4E-16	2.6E-11	7.0E-13	7.3E-11	2.6E-11	5.7E-13	2.2E-11	8.6E-13
	Clay/mineral	2.1E-11	4.2E-13	1.7E-11	2.7E-11	5.0E-12	3.2E-11	1.8E-11	8.3E-14	2.5E-11	6.5E-11	4.7E-14	7.0E-11	5.8E-11	1.3E-12	4.7E-16	2.8E-11	7.8E-13	8.6E-11	2.3E-11	7.8E-13	2.4E-11	8.2E-13
Tributary rivers	Peat	1.8E-15	2.5E-13	3.7E-15	2.1E-15	3.7E-17	8.7E-13	2.0E-16	6.2E-17	1.8E-15	7.5E-15	3.4E-18	6.1E-14	1.0E-14	9.9E-15	1.8E-22	1.9E-16	4.0E-17	2.3E-15	4.5E-13	1.9E-16	3.4E-13	3.0E-17
	Mud/gyttja	2.5E-15	2.6E-13	1.9E-17	2.7E-15	3.4E-17	9.0E-13	9.7E-17	8.3E-17	7.0E-16	9.8E-15	2.3E-18	6.4E-14	8.8E-15	7.7E-15	2.4E-22	1.6E-15	9.6E-18	1.3E-15	5.3E-13	1.4E-16	5.2E-13	5.0E-17
	Clay/mineral	1.7E-16	2.8E-13	1.9E-15	3.8E-16	5.3E-18	8.1E-13	4.2E-17	4.3E-17	6.9E-17	1.6E-15	5.4E-19	5.8E-15	9.9E-15	6.0E-15	1.2E-23	1.3E-17	3.4E-18	4.2E-16	5.1E-13	4.6E-17	4.5E-13	2.0E-18
Local rivers	Peat	8.3E-16	2.1E-15	2.2E-15	8.8E-16	1.8E-17	7.1E-14	1.5E-16	1.2E-17	9.4E-16	2.7E-15	1.6E-18	1.9E-15	5.5E-15	1.6E-15	1.4E-23	1.3E-16	2.7E-17	8.8E-16	2.2E-13	8.9E-17	1.5E-13	7.9E-18
	Mud/gyttja	7.5E-16	2.0E-15	1.4E-17	8.6E-16	1.6E-17	4.7E-14	8.0E-17	7.8E-18	2.2E-16	2.0E-15	2.6E-19	2.3E-15	3.3E-15	1.4E-15	1.4E-23	1.4E-15	2.4E-18	4.0E-16	2.2E-13	7.4E-17	1.6E-13	8.3E-18
	Clay/mineral	1.6E-17	2.0E-15	4.3E-15	2.1E-16	1.7E-18	6.7E-14	3.5E-17	2.1E-17	7.1E-18	6.6E-16	3.6E-19	5.7E-17	9.0E-15	5.3E-17	2.2E-24	5.2E-18	3.2E-18	1.7E-16	3.3E-14	3.0E-17	4.7E-14	1.6E-19
Regional rivers	Peat	1.7E-15	9.0E-17	2.4E-15	9.5E-16	2.9E-17	5.5E-14	4.3E-16	1.5E-17	1.1E-15	2.7E-15	1.8E-18	1.8E-15	5.2E-15	1.7E-15	3.3E-23	1.3E-16	2.5E-17	5.6E-16	2.2E-13	1.0E-16	1.7E-13	6.4E-18
	Mud/gyttja	8.1E-16	8.9E-17	1.4E-17	9.0E-16	1.2E-17	4.1E-14	1.1E-16	5.1E-18	2.1E-16	2.7E-15	2.5E-19	1.6E-15	3.6E-15	1.1E-15	1.4E-23	1.5E-15	2.2E-18	4.0E-16	2.7E-13	7.7E-17	1.3E-13	6.3E-18
	Clay/mineral	2.1E-17	2.2E-17	7.3E-15	2.5E-16	3.0E-18	1.1E-13	3.1E-17	1.9E-17	5.7E-18	6.8E-16	6.8E-19	1.2E-17	7.4E-15	2.0E-17	1.1E-24	4.3E-18	3.2E-18	2.5E-16	3.2E-14	3.2E-17	3.0E-14	1.9E-19
Small lakes - forest	Peat	1.1E-14	1.8E-16	4.5E-15	1.2E-14	2.5E-17	3.4E-14	4.4E-15	1.8E-17	7.4E-15	2.2E-14	1.7E-18	1.5E-14	1.7E-13	4.4E-15	7.2E-22	8.6E-15	5.4E-17	1.3E-14	5.9E-13	5.6E-17	4.6E-13	4.6E-16
	Mud/gyttja	7.5E-15	1.8E-16	4.5E-15	8.0E-15	4.2E-17	7.6E-14	4.3E-15	1.9E-17	2.4E-15	1.3E-14	1.1E-18	1.1E-14	1.6E-13	9.5E-16	4.9E-22	2.3E-14	3.9E-17	8.4E-15	6.3E-13	5.2E-17	5.2E-13	2.9E-16
	Clay/mineral	4.3E-15	1.8E-16	1.3E-15	3.8E-15	1.4E-17	6.2E-14	5.0E-15	3.2E-17	1.3E-15	5.8E-15	4.3E-19	6.6E-15	2.3E-13	2.3E-15	4.2E-23	7.9E-15	2.6E-17	4.4E-15	4.0E-13	5.2E-17	3.5E-13	1.1E-16
medium lakes - forest	Peat	8.2E-14	1.1E-17	4.3E-14	9.4E-14	4.4E-16	1.0E-13	2.4E-14	2.4E-16	7.6E-14	1.8E-13	1.8E-17	1.3E-13	4.1E-13	2.7E-14	5.6E-22	2.0E-14	3.6E-16	6.6E-14	4.1E-12	5.7E-16	3.0E-12	4.8E-16
	Mud/gyttja	4.9E-14	9.3E-18	5.6E-14	5.9E-14	4.3E-16	2.2E-13	1.8E-14	1.2E-16	2.4E-14	1.1E-13	1.1E-17	9.1E-14	3.9E-13	6.0E-15	6.1E-22	7.1E-14	3.5E-16	6.1E-14	2.9E-12	3.5E-16	2.7E-12	4.2E-16
	Clay/mineral	2.7E-14	1.3E-18	2.3E-14	3.1E-14	1.4E-16	1.4E-13	2.4E-14	1.8E-16	1.5E-14	6.4E-14	5.7E-18	4.7E-14	2.4E-13	1.2E-14	4.3E-23	7.4E-14	2.4E-16	3.1E-14	1.3E-12	5.2E-16	1.4E-12	8.7E-17
large lakes forest	Peat	7.4E-14	1.1E-17	3.2E-14	8.0E-14	3.0E-16	9.8E-14	2.5E-14	1.6E-16	8.0E-14	1.9E-13	2.3E-17	1.4E-13	4.1E-13	2.9E-14	3.3E-22	2.1E-14	4.6E-16	6.3E-14	4.9E-12	6.0E-16	4.3E-12	2.7E-16
	Mud/gyttja	1.0E-13	1.2E-17	5.7E-14	9.6E-14	5.4E-16	1.0E-13	2.4E-14	1.7E-16	8.3E-14	2.2E-13	2.0E-17	1.4E-13	2.4E-13	2.9E-14	3.5E-22	1.7E-14	3.5E-16	6.5E-14	4.4E-12	4.6E-16	3.1E-12	3.1E-16
	Clay/mineral	2.8E-14	1.3E-18	2.2E-14	3.0E-14	2.0E-16	1.5E-13	2.3E-14	2.0E-16	1.7E-14	8.0E-14	6.7E-18	5.9E-14	2.4E-13	1.2E-14	3.6E-23	8.7E-14	3.1E-16	3.4E-14	1.7E-12	5.9E-16	9.7E-13	6.4E-17
small lakes - agriculture	Peat	8.4E-15	4.4E-16	3.8E-14	5.8E-15	8.9E-17	4.2E-13	4.3E-15	7.1E-17	4.4E-15	1.3E-14	6.5E-18	8.1E-15	1.5E-13	1.2E-14	7.9E-22	7.4E-15	1.8E-16	6.9E-15	6.4E-13	6.9E-16	5.3E-13	2.5E-16
	Mud/gyttja	9.0E-15	4.4E-16	1.4E-16	7.7E-15	5.9E-17	4.1E-13	3.0E-15	7.2E-17	1.4E-15	1.4E-14	2.5E-18	9.5E-15	1.6E-13	1.3E-14	7.0E-22	3.8E-14	4.7E-17	5.2E-15	7.7E-13	1.0E-15	7.0E-13	3.7E-16
	Clay/mineral	2.8E-16	6.9E-17	4.5E-15	9.0E-16	1.1E-17	4.4E-13	1.6E-15	6.7E-17	7.6E-17	2.6E-15	1.5E-18	1.6E-16	1.2E-13	2.3E-16	3.6E-23	2.7E-16	2.3E-17	1.3E-15	2.3E-13	2.1E-16	2.5E-13	1.3E-17
medium lakes agriculture	Peat	3.8E-14	4.4E-16	1.6E-13	4.3E-14	1.2E-15	9.2E-13	3.4E-14	6.1E-16	3.8E-14	1.3E-13	6.3E-17	6.7E-14	3.9E-13	6.8E-14	3.9E-22	2.9E-14	1.4E-15	3.9E-14	3.2E-12	4.7E-15	3.5E-12	2.5E-16
	Mud/gyttja	3.7E-14	4.6E-16	1.0E-15	4.1E-14	6.2E-16	6.9E-13	1.6E-14	4.5E-16	1.1E-14	1.1E-13	1.6E-17	8.5E-14	3.1E-13	6.3E-14	4.3E-22	2.5E-13	1.1E-16	2.2E-14	3.5E-12	4.3E-15	3.5E-12	3.1E-16
	Clay/mineral	1.2E-15	1.4E-17	7.5E-14	9.6E-15	1.2E-16	1.0E-12	8.5E-15	5.7E-16	4.8E-16	2.5E-14	1.5E-17	8.6E-16	3.4E-13	9.1E-16	3.0E-23	1.2E-15	1.8E-16	9.5E-15	6.2E-13	1.5E-15	6.6E-13	1.0E-17
large lakes - agriculture	Peat	4.4E-14	4.4E-16	1.4E-13	4.1E-14	1.3E-15	8.7E-13	3.6E-14	6.5E-16	3.9E-14	1.4E-13	5.7E-17	6.9E-14	2.5E-13	5.8E-14	3.1E-22	2.9E-14	1.3E-15	3.8E-14	3.6E-12	3.9E-15	4.2E-12	2.0E-16
	Mud/gyttja	2.6E-14	4.4E-16	5.6E-15	2.6E-14	1.1E-15	5.2E-13	2.4E-14	2.5E-16	2.5E-14	6.5E-14	1.0E-17	4.9E-14	2.3E-13	5.2E-14	2.5E-22	2.4E-13	1.0E-16	4.1E-14	3.1E-12	2.3E-15	2.6E-12	1.3E-16
	Clay/mineral	9.7E-16	1.3E-17	5.5E-14	1.2E-14	1.3E-16	1.1E-12	8.3E-15	5.7E-16	4.6E-16	2.5E-14	1.7E-17	7.1E-16	2.2E-13	8.4E-16	2.0E-23	1.2E-15	1.7E-16	7.8E-15	5.7E-13	1.7E-15	6.4E-13	6.2E-18
Sea	Bay	8.4E-16	0	1.1E-20	8.2E-16	5.6E-19	5.4E-14	2.6E-19	9.3E-18	2.7E-16	4.2E-15	7.2E-19	3.0E-17	1.8E-16	1.2E-14	2.5E-22	3.1E-17	1.6E-16	4.6E-15	7.3E-17	7.1E-16	3.6E-16	9.5E-17
	Open Sea	1.7E-20	0	2.5E-25	1.5E-20	7.6E-24	1.1E-18	5.3E-24	2.0E-22	4.6E-21	5.9E-20	1.2E-23	6.8E-22	3.0E-21	1.8E-19	8.2E-27	4.9E-22	3.9E-21	9.1E-20	1.5E-21	1.1E-20	8.7E-21	3.0E-21

Arithmetic mean of calculated DCF: 1000 LHS samples for total dose over all pathways dose

Median		Am-243	C-14	Cl-36	Cm-245	Cs-135	I-129	Nb-94	Ni-59	Np-237	Pa-231	Pd-107	Pu-239	Ra-226	Se-79	Sm-151	Sn-126	Tc-99	Th-229	U-238	Zr-93	U-235	Am-241
Accumulation/ Exposure	Peat	1.2E-12	2.8E-13	7.5E-13	1.2E-12	1.5E-13	1.4E-11	1.9E-13	1.8E-14	1.3E-12	4.7E-12	9.7E-15	3.6E-12	4.7E-12	2.5E-13	2.8E-17	3.3E-13	2.9E-14	2.9E-12	8.2E-12	3.5E-14	7.7E-12	8.0E-14
	Mud/gyttja	1.1E-12	2.8E-13	7.4E-13	1.3E-12	1.5E-13	1.4E-11	1.9E-13	1.7E-14	1.4E-12	5.0E-12	8.5E-15	3.4E-12	4.6E-12	2.5E-13	2.8E-17	3.3E-13	2.6E-14	3.0E-12	8.0E-12	3.9E-14	7.9E-12	8.2E-14
	Clay/mineral	1.1E-12	2.8E-13	7.6E-13	1.1E-12	1.5E-13	1.5E-11	1.5E-13	2.0E-14	1.3E-12	4.6E-12	8.3E-15	3.8E-12	4.7E-12	2.5E-13	2.7E-17	3.0E-13	3.2E-14	3.6E-12	8.4E-12	3.7E-14	8.8E-12	7.7E-14
Bedrock wells	Peat	8.3E-12	8.6E-14	9.1E-14	8.5E-12	1.4E-13	3.7E-12	3.9E-14	1.5E-14	4.5E-12	2.8E-11	9.1E-15	1.0E-11	1.4E-11	9.4E-14	4.1E-15	9.2E-14	9.4E-15	2.5E-11	3.3E-12	1.6E-14	3.3E-12	8.2E-12
	Mud/gyttja	3.5E-11	8.5E-14	2.3E-13	3.4E-11	7.2E-13	5.2E-12	3.2E-11	3.5E-14	2.8E-11	9.3E-11	2.2E-14	4.1E-11	6.0E-11	2.6E-13	4.2E-15	3.8E-11	7.1E-14	1.0E-10	6.2E-12	7.0E-14	5.4E-12	1.2E-11
	Clay/mineral	3.5E-11	8.7E-14	2.4E-13	3.8E-11	6.2E-13	5.0E-12	3.5E-11	3.3E-14	2.8E-11	9.1E-11	2.2E-14	3.7E-11	5.7E-11	2.6E-13	4.1E-15	3.6E-11	6.9E-14	1.0E-10	5.5E-12	6.6E-14	6.2E-12	1.2E-11
Overburden Wells	Peat	3.4E-12	2.9E-13	1.2E-12	3.5E-12	2.3E-13	1.4E-11	2.6E-12	2.4E-14	4.5E-12	1.1E-11	1.2E-14	7.3E-12	1.0E-11	2.9E-13	3.5E-17	2.8E-12	4.0E-14	9.7E-12	7.6E-12	4.3E-14	7.9E-12	1.3E-13
	Mud/gyttja	3.6E-12	2.7E-13	1.1E-12	3.3E-12	2.1E-13	1.4E-11	2.3E-12	2.3E-14	3.8E-12	1.1E-11	1.2E-14	8.2E-12	9.1E-12	2.9E-13	3.6E-17	3.2E-12	4.4E-14	9.8E-12	7.4E-12	3.9E-14	7.5E-12	1.2E-13
	Clay/mineral	3.4E-12	2.7E-13	1.1E-12	3.7E-12	2.4E-13	1.3E-11	2.3E-12	2.3E-14	4.2E-12	1.2E-11	1.2E-14	7.6E-12	1.0E-11	2.9E-13	3.4E-17	3.1E-12	3.8E-14	9.5E-12	7.8E-12	3.8E-14	7.7E-12	1.1E-13
Tributary rivers	Peat	2.6E-16	7.3E-14	1.6E-16	2.7E-16	4.4E-18	1.7E-13	2.1E-17	6.7E-18	2.3E-16	1.1E-15	3.4E-19	4.0E-15	1.3E-15	1.4E-15	2.5E-23	2.7E-17	4.1E-18	3.4E-16	4.8E-14	1.9E-17	4.8E-14	3.4E-18
	Mud/gyttja	3.5E-16	7.3E-14	1.1E-18	3.8E-16	2.9E-18	1.9E-13	6.4E-18	1.2E-17	7.1E-17	1.6E-15	3.3E-19	6.8E-15	1.2E-15	1.5E-15	3.3E-23	2.1E-16	1.4E-18	1.7E-16	8.0E-14	2.1E-17	6.6E-14	6.9E-18
	Clay/mineral	2.2E-17	7.2E-14	1.3E-16	4.5E-17	5.4E-19	2.1E-13	5.7E-18	4.5E-18	9.6E-18	1.7E-16	6.2E-20	5.7E-16	7.6E-16	1.1E-15	1.6E-24	2.0E-18	4.2E-19	4.2E-17	9.7E-14	7.1E-18	9.2E-14	3.0E-19
Local rivers	Peat	1.1E-16	6.9E-16	1.4E-16	1.1E-16	1.5E-18	8.4E-15	1.8E-17	1.0E-18	1.1E-16	3.1E-16	1.4E-19	2.5E-16	3.5E-16	1.5E-16	1.3E-24	1.5E-17	2.3E-18	7.3E-17	1.8E-14	6.7E-18	1.5E-14	6.0E-19
	Mud/gyttja	9.0E-17	7.1E-16	7.0E-19	1.0E-16	1.2E-18	6.8E-15	5.9E-18	8.8E-19	2.3E-17	2.7E-16	2.3E-20	2.9E-16	3.5E-16	1.9E-16	1.7E-24	2.1E-16	1.1E-19	3.6E-17	1.8E-14	4.2E-18	1.5E-14	8.3E-19
	Clay/mineral	2.3E-18	6.2E-16	1.4E-16	1.7E-17	1.9E-19	1.0E-14	5.2E-18	8.5E-19	9.0E-19	5.6E-17	2.4E-20	7.0E-18	3.5E-16	1.3E-17	9.9E-26	5.2E-19	1.9E-19	1.5E-17	4.8E-15	2.5E-18	3.9E-15	1.6E-20
Regional rivers	Peat	1.0E-16	2.7E-17	1.4E-16	1.1E-16	1.5E-18	5.3E-15	1.9E-17	7.8E-19	1.0E-16	3.6E-16	1.3E-19	1.5E-16	3.5E-16	1.1E-16	1.0E-24	1.4E-17	2.3E-18	6.5E-17	1.6E-14	5.5E-18	1.3E-14	5.5E-19
	Mud/gyttja	8.3E-17	2.8E-17	6.9E-19	8.9E-17	1.2E-18	4.0E-15	5.5E-18	7.9E-19	2.0E-17	2.5E-16	1.5E-20	1.7E-16	3.2E-16	1.6E-16	9.6E-25	2.0E-16	8.2E-20	3.5E-17	1.7E-14	4.6E-18	1.6E-14	7.2E-19
	Clay/mineral	1.8E-18	8.2E-18	1.4E-16	1.6E-17	1.7E-19	7.5E-15	5.7E-18	8.5E-19	7.6E-19	4.6E-17	2.5E-20	1.2E-18	3.4E-16	3.5E-18	7.2E-26	5.2E-19	1.8E-19	1.5E-17	3.3E-15	2.1E-18	2.7E-15	1.2E-20
Small lakes - forest	Peat	1.1E-15	5.2E-17	6.5E-16	1.1E-15	2.3E-18	5.6E-15	4.4E-16	1.2E-18	9.8E-16	1.9E-15	8.2E-20	1.3E-15	1.2E-14	2.2E-16	3.7E-23	7.9E-16	2.5E-18	1.4E-15	6.3E-14	7.2E-18	5.4E-14	3.2E-17
	Mud/gyttja	1.4E-15	4.9E-17	2.8E-16	1.4E-15	1.8E-18	1.5E-14	3.3E-16	2.0E-18	3.4E-16	2.5E-15	9.5E-20	1.9E-15	1.1E-14	1.3E-16	4.8E-23	3.4E-15	2.7E-18	1.1E-15	9.1E-14	9.1E-18	8.4E-14	4.8E-17
	Clay/mineral	2.2E-16	5.0E-17	4.1E-17	2.2E-16	4.4E-19	1.1E-14	6.6E-16	1.1E-18	9.0E-17	3.8E-16	1.6E-20	3.0E-16	7.5E-15	1.4E-16	3.1E-24	9.1E-16	7.2E-19	2.6E-16	5.7E-14	5.8E-18	5.9E-14	5.5E-18
medium lakes - forest	Peat	2.0E-14	3.7E-18	6.7E-15	2.2E-14	5.2E-17	2.5E-14	4.7E-15	1.7E-17	2.3E-14	4.4E-14	2.2E-18	3.0E-14	4.1E-14	2.5E-15	1.1E-22	5.2E-15	3.9E-17	1.7E-14	9.2E-13	1.2E-16	5.6E-13	1.1E-16
	Mud/gyttja	1.9E-14	3.7E-18	1.1E-14	1.9E-14	5.9E-17	6.8E-14	4.8E-15	2.3E-17	7.9E-15	3.8E-14	1.8E-18	2.8E-14	3.9E-14	1.1E-15	1.5E-22	2.7E-14	4.0E-17	2.0E-14	9.9E-13	9.7E-17	6.9E-13	1.3E-16
	Clay/mineral	7.4E-15	6.0E-19	2.5E-15	8.2E-15	2.5E-17	4.1E-14	7.7E-15	3.3E-17	3.9E-15	1.8E-14	7.9E-19	1.3E-14	3.7E-14	1.5E-15	9.2E-24	1.9E-14	2.9E-17	9.2E-15	3.2E-13	1.6E-16	2.3E-13	2.0E-17
large lakes forest	Peat	1.9E-14	3.5E-18	5.4E-15	1.9E-14	5.3E-17	2.5E-14	4.2E-15	1.5E-17	2.2E-14	4.7E-14	2.2E-18	2.8E-14	2.7E-14	2.3E-15	7.1E-23	4.6E-15	3.7E-17	1.5E-14	8.9E-13	9.6E-17	7.0E-13	7.1E-17
	Mud/gyttja	1.7E-14	3.2E-18	5.8E-15	1.9E-14	4.6E-17	2.4E-14	3.8E-15	1.5E-17	2.1E-14	4.4E-14	2.1E-18	3.0E-14	2.6E-14	2.1E-15	6.7E-23	4.8E-15	3.7E-17	1.4E-14	8.8E-13	9.6E-17	5.9E-13	6.6E-17
	Clay/mineral	7.1E-15	5.5E-19	3.2E-15	7.6E-15	2.8E-17	3.7E-14	7.6E-15	3.5E-17	4.0E-15	1.7E-14	9.3E-19	1.5E-14	2.8E-14	1.4E-15	5.0E-24	2.3E-14	3.3E-17	8.2E-15	3.2E-13	1.5E-16	2.3E-13	1.2E-17
small lakes - agriculture	Peat	7.7E-16	2.1E-16	2.7E-15	7.2E-16	8.5E-18	7.7E-14	5.6E-16	9.6E-18	7.3E-16	1.5E-15	6.9E-19	9.4E-16	1.9E-14	1.7E-15	4.3E-23	8.4E-16	2.6E-17	1.0E-15	6.9E-14	6.7E-17	8.3E-14	2.5E-17
	Mud/gyttja	1.0E-15	2.1E-16	7.1E-18	1.0E-15	4.9E-18	5.8E-14	1.9E-16	1.3E-17	1.7E-16	2.1E-15	1.8E-19	1.4E-15	1.7E-14	2.6E-15	4.8E-23	6.2E-15	1.1E-18	4.2E-16	9.5E-14	5.8E-17	1.1E-13	3.6E-17
	Clay/mineral	3.0E-17	3.1E-17	2.3E-16	9.3E-17	7.8E-19	1.1E-13	2.3E-16	5.2E-18	8.6E-18	1.9E-16	7.4E-20	2.1E-17	1.1E-14	5.3E-17	3.5E-24	2.1E-17	1.5E-18	1.0E-16	5.5E-14	1.9E-17	5.7E-14	1.2E-18
medium lakes agriculture	Peat	1.1E-14	2.1E-16	2.2E-14	1.2E-14	1.6E-16	3.0E-13	8.2E-15	1.2E-16	1.2E-14	3.0E-14	1.3E-17	1.6E-14	8.3E-14	1.3E-14	6.8E-23	9.0E-15	3.3E-16	1.1E-14	8.8E-13	8.4E-16	9.0E-13	5.6E-17
	Mud/gyttja	1.2E-14	2.1E-16	8.7E-17	1.3E-14	1.0E-16	2.1E-13	2.8E-15	1.0E-16	3.0E-15	3.0E-14	2.2E-18	2.1E-14	7.4E-14	2.1E-14	7.9E-23	1.0E-13	1.2E-17	5.0E-15	1.0E-12	6.0E-16	1.0E-12	9.3E-17
	Clay/mineral	2.7E-16	8.9E-18	6.6E-15	1.6E-15	1.6E-17	3.5E-13	3.1E-15	9.2E-17	1.2E-16	4.2E-15	1.9E-18	1.6E-16	6.2E-14	3.9E-16	4.6E-24	2.5E-16	2.2E-17	1.7E-15	2.3E-13	3.1E-16	2.3E-13	2.2E-18
large lakes - agriculture	Peat	1.1E-14	2.1E-16	2.0E-14	1.0E-14	1.6E-16	2.9E-13	7.9E-15	1.0E-16	1.2E-14	2.9E-14	1.3E-17	1.5E-14	5.4E-14	1.2E-14	4.2E-23	7.3E-15	3.1E-16	8.4E-15	9.8E-13	7.5E-16	1.0E-12	3.3E-17
	Mud/gyttja	5.2E-15	2.0E-16	8.9E-16	5.9E-15	1.9E-16	1.8E-13	6.4E-15	4.3E-17	6.6E-15	1.6E-14	1.0E-18	1.0E-14	5.9E-14	1.6E-14	3.6E-23	7.9E-14	1.1E-17	1.1E-14	6.5E-13	3.5E-16	6.3E-13	2.1E-17
	Clay/mineral	2.7E-16	8.4E-18	8.5E-15	1.6E-15	1.8E-17	3.1E-13	2.6E-15	9.2E-17	1.1E-16	4.4E-15	2.0E-18	1.3E-16	4.3E-14	3.2E-16	2.8E-24	2.3E-16	2.4E-17	1.6E-15	2.2E-13	2.7E-16	2.2E-13	1.4E-18
Sea	Bay	5.6E-17	0	2.8E-21	6.2E-17	5.4E-20	1.5E-14	3.9E-20	1.4E-18	1.6E-17	2.5E-16	7.0E-20	3.9E-18	2.7E-17	1.8E-15	2.7E-23	3.7E-18	3.7E-17	4.7E-16	1.1E-17	5.0E-17	4.5E-17	6.2E-18
	Open Sea	1.6E-21	0	7.8E-26	1.7E-21	1.5E-24	4.4E-19	9.7E-25	3.2E-23	3.8E-22	6.1E-21	1.7E-24	9.5E-23	9.2E-22	4.5E-20	1.4E-27	8.0E-23	1.0E-21	1.1E-20	3.0E-22	1.3E-21	1.1E-21	2.8E-22

Median of calculated DCF: 1000 LHS samples for total dose over all pathways dose. Results for geometric mean a similar.

APPENDIX E – Results for Sensitivity analysis

The following table lists the results for the Standardised Rank Regressions Coefficients (SRRC) calculated for selected radionuclides for the most significant landscape objects for dose as identified in Section 4. The SRRC is chosen for the analysis since it gives a good indication of the contribution to overall uncertainty and has been found to be the most robust reliable estimator of uncertainty (Campolongo *et al.*, 2000).

For each of the seven radionuclides identified in Section 4.3 as of importance to long-term dose assessment in Finland, the top ten parameters contributing to dose have been ranked according to absolute magnitude of the SRRC, allowing for both positive and negative correlations. Values for which SRRC < 0.1 are assumed to be of little importance and are greyed-out. Parameter names are those given in Appendices B and C.

Bedrock 1 year	C-14		Cl-36		Ni-59		Sn-126		I-129		Cs-135		Ra-226
Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC
Qdil	-0.99	Qdil	-0.82	Qdil	-0.86	Qdil	-0.99	Qdil	-0.94	Qdil	-0.91	Qdil	-0.98
TR_milk [C-14]	0.12	K_p [Cl-36]	0.25	TR_meat [Ni-59]	0.45	r_irri [Sn-126]	0.08	TR_milk [I-129]	0.31	TR_milk [Cs-135]	0.28	r_irri [Ra-226]	0.09
r_irri [C-14]	0.10	TR_milk [Cl-36]	0.23	r_irri [Ni-59]	0.09	l_T	-0.04	r_irri [I-129]	0.11	TR_meat [Cs-135]	0.16	TR_milk [Ra-226]	0.07
TR_meat [C-14]	0.08	rho_topSoil	-0.19	TR_milk [Ni-59]	0.08	rho_topSoil	0.00	TR_meat [I-129]	0.05	r_irri [Cs-135]	0.10	TR_meat [Ra-226]	0.07
rho_topSoil	0.00	KD_regoUp_ter [Cl-36]	0.18	l_T	-0.01	TR_milk [Sn-126]	0.00	P	-0.01	K_f [Cs-135]	-0.01	rho_topSoil	-0.01
KD_regoPeat [C-14]	0.00	TR_meat [Cl-36]	0.18	KD_regoUp_ter [Ni-59]	0.01	K_cereal [Sn-126]	0.00	KD_regoUp_ter [I-129]	0.01	K_crust_fw [Cs-135]	-0.01	K_f [Ra-226]	0.01
KD_regoUp_ter [C-14]	0.00	r_irri [Cl-36]	0.05	rho_topSoil	0.01	KD_regoPeat [Sn-126]	0.00	rho_topSoil	-0.01	K_cereal [Cs-135]	0.01	K_cereal [Ra-226]	0.00
K_fish_fw [C-14]	0.00	l_T	-0.05	rho_deepSoil	-0.01	Af	0.00	l_D	0.00	K_m [Cs-135]	0.01	K_fish_fw [Ra-226]	0.00
eps_deepSoil	0.00	K_f [Cl-36]	0.03	KD_regoPeat [Ni-59]	-0.01	K_f [Sn-126]	0.00	K_cereal [I-129]	0.00	l_T	0.01	TR_game [Ra-226]	0.00
l_D	0.00	K_cereal [Cl-36]	0.02	K_gveg [Ni-59]	0.01	K_crust_fw [Sn-126]	0.00	TR_game [I-129]	0.00	P	-0.01	l_T	0.00

OBW 10 kyear	C-14		Cl-36		Ni-59		Sn-126		I-129		Cs-135		Ra-226
Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC
Af_OBW	-0.66	KD_regoUp_ter [Cl-36]	0.72	KD_regoLow [Ni-59]	-0.73	KD_regoLow [Sn-126]	-0.79	Af_OBW	-0.48	KD_regoLow [Cs-135]	-0.80	KD_regoLow [Ra-226]	-0.75
P	-0.57	P	-0.36	TR_meat [Ni-59]	0.34	KD_regoUp_ter [Sn-126]	0.42	TR_milk [I-129]	0.41	KD_regoUp_ter [Cs-135]	0.45	KD_regoUp_ter [Ra-226]	0.39
KD_regoLow [C-14]	-0.25	K_p [Cl-36]	0.32	KD_regoUp_ter [Ni-59]	0.34	Af_OBW	-0.20	P	-0.37	Af_OBW	-0.19	Af_OBW	-0.30
TR_milk [C-14]	0.19	Af_OBW	-0.26	Af_OBW	-0.27	l_well_OBW	-0.18	KD_regoLow [I-129]	-0.37	TR_milk [Cs-135]	0.11	l_well_OBW	-0.26
r_irri [C-14]	0.16	TR_milk [Cl-36]	0.19	l_well_OBW	-0.17	rho_topSoil_OBW	0.14	KD_regoUp_ter [I-129]	0.28	l_well_OBW	-0.11	K_cereal [Ra-226]	0.16
TR_meat [C-14]	0.12	TR_meat [Cl-36]	0.12	KD_regoPeat [Ni-59]	-0.10	KD_regoPeat [Sn-126]	-0.11	r_irri [I-129]	0.12	KD_regoPeat [Cs-135]	-0.10	K_f [Ra-226]	0.14
l_well_OBW	-0.08	rho_topSoil_OBW	-0.09	rho_topSoil_OBW	-0.09	P	-0.06	l_well_OBW	-0.11	rho_topSoil_OBW	-0.09	K_gveg [Ra-226]	0.10
rho_deepSoil_OBW	-0.03	K_f [Cl-36]	0.05	P	-0.08	l_T_OBW	-0.05	K_cereal [I-129]	0.09	K_p [Cs-135]	0.07	KD_regoPeat [Ra-226]	-0.08
rho_well_OBW	-0.03	K_cereal [Cl-36]	0.05	K_root [Ni-59]	0.07	rho_deepSoil_OBW	-0.05	K_p [I-129]	0.08	K_cereal [Cs-135]	0.07	P	-0.06
KD_regoPeat [C-14]	-0.03	K_m [Cl-36]	0.03	TR_milk [Ni-59]	0.06	rho_well_OBW	-0.04	TR_meat [I-129]	0.06	P	-0.06	eps_well_OBW	0.06

Acc/Exp 10025 year	C-14		Cl-36		Ni-59		Sn-126		I-129		Cs-135		Ra-226
Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC
P	-0.48	KD_regoUp_ter [Cl-36]	0.69	KD_regoLow [Ni-59]	-0.82	KD_regoLow [Sn-126]	-0.87	KD_regoLow [I-129]	-0.46	KD_regoLow [Cs-135]	-0.88	KD_regoLow [Ra-226]	-0.82
As	-0.47	K_p [Cl-36]	0.33	TR_meat [Ni-59]	0.31	Af	-0.24	TR_milk [I-129]	0.39	Af	-0.16	Af	-0.33
Af	-0.24	P	-0.28	Af	-0.23	l_LOB	-0.23	P	-0.31	l_LOB	-0.13	l_LOB	-0.27
TR_milk [C-14]	0.21	As	-0.24	l_LOB	-0.21	As	0.14	As	-0.28	TR_milk [Cs-135]	0.12	As	0.11
r_irri [C-14]	0.14	TR_milk [Cl-36]	0.21	KD_regoPeat [Ni-59]	0.10	KD_regoPeat [Sn-126]	-0.12	Af	-0.19	KD_regoPeat [Cs-135]	0.10	rho_D_acc	-0.09
TR_meat [C-14]	0.13	TR_meat [Cl-36]	0.16	eps_LOB	0.06	P	0.10	r_irri [I-129]	0.15	KD_regoUp_ter [Cs-135]	0.10	K_f [Ra-226]	0.09
KD_regoLow [C-14]	-0.08	KD_regoLow [Cl-36]	0.15	r_irri [Ni-59]	0.05	l_T	-0.08	KD_regoUp_ter [I-129]	0.13	TR_meat [Cs-135]	0.07	K_cereal [Ra-226]	0.08
v_geo	-0.05	Af	-0.14	l_T	-0.05	eps_LOB	0.06	l_LOB	-0.13	P	-0.04	KD_regoPeat [Ra-226]	0.07
K_crust_fw [C-14]	0.04	rho_D_acc	-0.13	TR_milk [Ni-59]	0.05	rho_LOB	-0.03	KD_regoPeat [I-129]	0.11	rho_D_acc	-0.04	eps_LOB	0.06
rho_LOB	-0.03	l_T	-0.11	KD_regoUp_ter [Ni-59]	0.05	KD_regoUp_ter [Sn-126]	0.03	TR_meat [I-129]	0.10	K_p [Cs-135]	0.03	K_gveg [Ra-226]	0.06

Tributary River	C-14		Cl-36		Ni-59		Sn-126		I-129		Cs-135		Ra-226
Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC	Parameter	SRCC
Af_RAgri	-0.70	Af_RAgri	-0.52	Af_RAgri	-0.64	Af_RAgri	-0.60	Af_RAgri	-0.66	Af_RAgri	-0.57	Af_RAgri	-0.63
As_RAgri	0.41	KD_regoLow [Cl-36]	-0.35	KD_regoLow [Ni-59]	-0.44	KD_regoLow [Sn-126]	-0.41	KD_regoLow [I-129]	-0.44	KD_regoLow [Cs-135]	-0.39	KD_regoLow [Ra-226]	-0.43
K_fish_fw [C-14]	0.36	As_RAgri	0.32	As_RAgri	0.39	As_RAgri	0.35	As_RAgri	0.39	As_RAgri	0.35	As_RAgri	0.38
KD_regoLow [C-14]	-0.31	KD_regoPG [Cl-36]	-0.32	TR_meat [Ni-59]	0.35	KD_regoUp_drain [Sn-126]	0.30	l_LOB_RAgri	-0.23	KD_regoPG [Cs-135]	-0.33	KD_regoPG [Ra-226]	-0.24
l_LOB_RAgri	-0.24	K_p [Cl-36]	0.26	l_LOB_RAgri	-0.24	KD_regoPG [Sn-126]	-0.25	TR_milk [I-129]	0.23	l_LOB_RAgri	-0.20	l_LOB_RAgri	-0.23
P	-0.10	l_LOB_RAgri	-0.20	P	-0.08	l_LOB_RAgri	-0.21	P	-0.09	K_fish_fw [Cs-135]	0.17	eps_deepSoil_RAgri	0.12
eps_LOB_RAgri	0.05	eps_deepSoil_RAgri	0.19	KD_regoPG [Ni-59]	-0.07	eps_deepSoil_RAgri	0.12	r_irri [I-129]	0.08	KD_regoUp_drain [Cs-135]	0.16	l_D_RAgri	-0.10
rho_LOB_RAgri	-0.05	l_D_RAgri	-0.17	eps_LOB_RAgri	0.06	P	-0.10	eps_LOB_RAgri	0.07	eps_deepSoil_RAgri	0.15	K_f [Ra-226]	0.09
TR_milk [C-14]	0.03	KD_regoUp_drain [Cl-36]	0.16	r_irri [Ni-59]	0.06	l_D_RAgri	-0.10	rho_LOB_RAgri	-0.05	l_D_RAgri	-0.14	K_cereal [Ra-226]	0.08
TR_meat[C-14]	0.02	TR_milk[Cl-36]	0.16	rho_LOB_RAgri	-0.05	eps_LOB_RAgri	0.06	KD_regoPG [I-129]	-0.05	TR_milk [Cs-135]	0.11	P	-0.08

Results for probabilistic sensitivity analysis using standardised rank regression coefficient, selected radionuclides and landscape objects.

APPENDIX F – Interparameter correlations: Accumulation and Exposure model for peat

The material in this appendix sets out an investigation of the potential effect of interparameter correlations on the calculated DCF values. In the well models (bedrock and OB wells) the way the models are configured means that the only missing "correlation" is between the physical characteristics of the OB media – the thickness, density and porosity. With the accumulation/exposure scenario these models give the highest calculated doses and so are the focus of attention here.

For the accumulation/exposure model there is an issue that is of interest, namely the size (*As* m^2) of the diluting (uncontaminated) catchment that can provide water in the OB circulation to the contaminated area (*Af* m^2)

In the accumulation-Exposure model the following correlations are set as follows (all other parameters are uncorrelated):

The correlation between agricultural area and lake area means that combinations of large and small are less likely in the resulting parameter sets, and by correlating the soil layer thicknesses with the area of the model the larger objects are able to accumulate higher thicknesses of material.

Implemented correlation matrix.

	Af	*As*	*l_D_acc*	*l_LOB*	*l_T*
Af		0.7			
As				0.2	
l_D_acc					0.7
l_LOB			0.5		
l_T					

The difference in the correlation values reflects the expected strength of the correlation; the lower OB is less influenced by the long-term accumulation processes that are the mid- and upper OB layers.

In this case the correlations describing the properties of the upper OB relative to the mid-OB are not needed because there is a direct functional relationship between them. The material of the OB is the same in each compartment, implicitly then, the correlation is +1.0.

The four radionuclides from the main sensitivity analysis are considered, with the following results for the DCFs at the end of the simulation (at 10050 year after the simulation start). The table shows that the correlations have very little influence, as shown below:

	^{36}Cl		^{94}Nb	
	correlated	**uncorrelated**	**correlated**	**uncorrelated**
mean	6.5E-12	6.5E-12	4.6E-12	6.9E-12
median	8.6E-13	7.5E-13	1.9E-13	1.9E-13
std dev.	2.8E-11	3.5E-11	1.5E-11	2.9E-11
GM	1.0E-12	6.5E-12	4.6E-12	6.9E-12
GSD	6.2	5.9	19.1	21.1
	^{129}I		^{226}Ra	
	correlated	**uncorrelated**	**correlated**	**uncorrelated**
mean	3.1E-11	2.8E-11	3.2E-11	3.7E-11
median	1.6E-11	1.4E-11	5.3E-12	4.7E-12
std dev.	5.6E-11	5.0E-11	1.5E-10	2.0E-10
GM	3.1E-11	2.8E-11	3.2E-11	3.7E-11
GSD	3.3	3.3	7.8	7.9

Statistics comparing results from correlated and uncorrelated models.

	With correlations			Uncorrelated	
rank	**Output**	**SRRC**		**Output**	**SRRC**
1	KD_regoUp_ter [Cl-36]	0.67		KD_regoUp_ter [Cl-36]	0.70
2	K_p [Cl-36]	0.30		K_p [Cl-36]	0.33
3	P	–0.26		P	–0.26
4	TR_milk [Cl-36]	0.23		As	-0.22
5	As	–0.22		TR_milk [Cl-36]	0.21
6	KD_regoLow [Cl-36]	0.17		KD_regoLow [Cl-36]	0.17
7	TR_meat [Cl-36]	0.15		TR_meat [Cl-36]	0.16
8	I_T	–0.12		Af	–0.16
9	Af	–0.11		rho_D_acc	–0.12
10	rho_D_acc	–0.10		I_T	–0.10

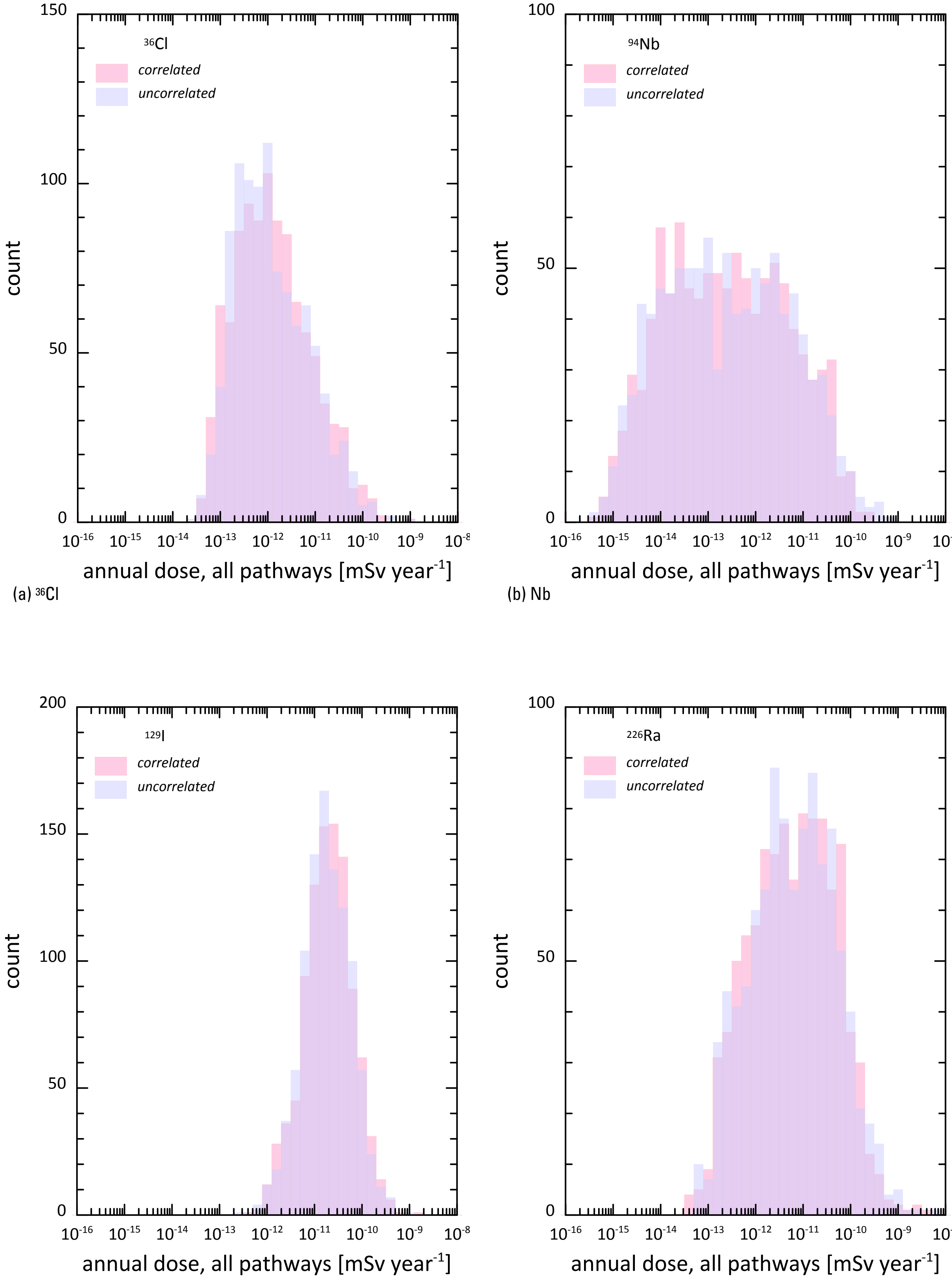
	With correlations			Uncorrelated	
rank	**Output**	**SRRC**		**Output**	**SRRC**
1	KD_regoLow [Ra-226]	–0.84		KD_regoLow [Ra-226]	–0.82
2	Af	–0.34		Af	–0.33
3	I_LOB	–0.28		I_LOB	–0.28
4	K_cereal [Ra-226]	0.10		As	0.10
5	rho_D_acc	–0.09		K_f [Ra-226]	0.09
6	KD_regoUp_ter [Ra-226]	0.08		rho_D_acc	–0.09
7	As	0.08		K_cereal [Ra-226]	0.09
8	K_f [Ra-226]	0.07		KD_regoUp_ter [Ra-226]	0.08
9	eps_LOB	0.07		K_gveg [Ra-226]	0.06
10	P	0.07		I_T	–0.06

Calculated standardise Rand Regression Coefficients (SRRC) for ^{36}Cl and ^{226}Ra in correlated and uncorrelated models. Results show marginal changes.

There is a marginal effect on the distributions but no overall impact on the results for the DCFs as they affect the RCL calculation (as shown above).

Similarly there is little influence on the parameters that are most sensitive for the calculated DCFs, here illustrated for ^{36}Cl (mobile) and ^{226}Ra (immobile). There is some reordering but the changes to the numerical values are negligible.

Form this brief analysis it is concluded that the models are robust in respect of the parameterisation used.



(a) ^{36}Cl (b) Nb

(c) ^{129}I (d) ^{226}Ra

Comparison of probability distribution functions for correlated and uncorrelated models.